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Thiokol

THIOKOL/ELKTON DIVISION

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NOZZLE INSERT EVALUATION TEST REPORT

NASA CONTRACT NAS1-11859
TASK ASSIGNMENT 3

A DIVISION OF THIOKOL CORPORATION

E45-77

THIOKOL CORPORATION
ELKTON DIVISION
ELKTON, MARYLAND

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PREPARED BY: E.C. Oosterom 4/12/77
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1.0 SUMMARY

This report represents the results of the static testing of two different rocket motors which utilized a new candidate nozzle throat insert material. The nozzle throat inserts were made of a material that shows advantages over presently used nozzle insert materials. The candidate insert of tantalum carbide and powdered graphite is molded at high temperature and pressures. The inserts were fabricated by Los Alamos Scientific Laboratory under a contract with NASA-LRC to configurations supplied by Thiokol. The inserts were installed in the nozzles at Thiokol.

The first test of the insert material was conducted in an Altair III rocket motor, S/N 2501-01, on December 9, 1976. The motor was conditioned to 75°F and test fired at ambient pressure conditions while spinning at 30 rpm. Results of the test indicate that the nozzle insert material was equivalent to the standard G-90 carbon insert material in throat erosion characteristics. This motor subjected the insert to a flame temperature of 5698°F for approximately 30 seconds.

The second test of the insert material was conducted with a 1000-pound spherical motor on January 27, 1977. The motor was conditioned to 75°F and test fired at ambient pressure conditions while spinning at 30 rpm. This motor subjected the insert to a flame temperature of 6055°F for approximately 60 seconds. The average erosion of the nozzle throat insert material was similar to that in the Altair and other 30-inch motor tests; the material did not show any distinct advantage over G-90 nozzle insert material for these size inserts. However, the backfit analysis indicates that the erosion was not uniform. For the first 30 seconds, the erosion rate was low, and for the last 30 seconds very high, indicating that the insert material may be going plastic. For this reason, the insert may not be adequate for long burn duration motors.

The carbide insert material is approximately three times as dense as G-90 and, therefore, heavier. In both motor tests, the carbide insert suffered severe erosion on the entrance section and, during cooldown after test, cracked severely.

2.0 CONCLUSIONS

The tantalum carbide inserts evaluated in the two tests described herein showed throat erosion equivalent to, or slightly less than, G-90 material tested in these same motors. Entrance section erosion was significantly worse, and some evidence of melting was also seen in the entrance sections. The inserts cracked severely as they cooled, and there was also evidence of nonhomogeneous erosion throughout the insert.

For those nozzles where G-90 billets can be obtained for the insert, there would be no advantage in using the tantalum carbide material. In fact, there would be disadvantages in cost and possible performance due to the entrance section erosion. NDT of the tantalum carbide insert is similar to that used for graphite (X-ray and process control).

For nozzles that require throat inserts larger than can be obtained from G-90 billets, the tantalum carbide may be more economical than other insert approaches (i.e., 3D carbon/carbon, PG packs) and perhaps simpler to make and NDT.

Further work is needed to optimize the carbide-to-graphite ratios to better resist the pockmarking (nonhomogeneity) seen in the two inserts tested. In addition, demonstration by test of the brazing technique for making larger diameter inserts is also required if this material is to be seriously considered for nozzle throat inserts. Finally, usage of the carbide insert in nozzle throats needs to be studied so the proper designs can be effected; i.e., thickness, configuration, and backup material and configuration, to help eliminate the entrance erosion problems and the cooldown cracking.

3.0 DISCUSSIONS

3.1 Test Configuration, Altair III Motor

Altair III rocket motor P/N UTC-B0686-01-02, S/N 2501-01, was provided by NASA as Government-furnished property (GFP). Thiokol removed nozzle S/N 04 from the motor and placed the nozzle in storage. Altair nozzle S/N 30205, also provided by NASA as Government-furnished property, was a residual nozzle from a previous order. This nozzle had a chip at the exit plane which was considered insignificant. The nozzle was subjected to a complete thermovision inspection at NASA-LRC prior to shipment to Thiokol for use as a comparison to the thermovision inspection during test. When received at Thiokol, the existing G-90 nozzle throat insert in nozzle S/N 30205 was machined out and the throat insert made from tantalum carbide installed using the approved procedure (Appendix A). The nozzle throat insert billet was molded at Kawecki Berylco in Reading, PA, under the supervision of Los Alamos personnel. The billet was molded under controlled temperature and pressure conditions. After molding, the billet was machined at Los Alamos to the configuration shown in VSD drawing 23-427002, Rev. A. The insert had a weight of 4.3 pounds, which is approximately three times that of the G-90 insert.

Altair igniter TE-P-648-1, P/N E25803-02, S/N 18, was also provided by NASA as Government-furnished property. This igniter was one of the oldest (approximately 3 years) Thiokol Altair igniters available and as such was used to demonstrate a shelf life capability of at least 3 years. The test motor conformed to Thiokol P/N E29436-01. The predicted burn time was 30 seconds. The propellant flame temperature was 5698°F.

The loaded case assembly, S/N 2501-01, was manufactured by United Technology Center (UTC) in February 1974. A companion motor, S/N 2501-02, cast from the same batch, was test fired on April 11, 1974, at AEDC at an average simulated altitude of 103,000 ft while spinning about the motor axial centerline at 180 rpm. The motor case temperature in motor S/N 2501-02 exceeded the specification limits after propellant burnout. The higher-than-normal case temperature was caused by approximately 10 pounds of slag which remained in the case after the propellant was expended. The propellant in these motors was UTC formulation UTP-3096A, which is an 84.5% total solids loaded propellant containing nominally 68.1% AP, 16.4% aluminum, and 15.5% polybutadiene-acrylic-acid-acrylonitrile (PBAN) polymer. The high amount of slag retained was attributed to the acceleration load on the firing surface during firing due to the spin environment. (The batch had a changed oxidizer bimodal to maintain burning rate).

3.2 Motor Tests, Altair III Motor

3.2.1 Pretest Inspection. The loaded case assembly from motor S/N 2501-01 was conditioned overnight at 35°F and then radiographically inspected at the conditioned temperature. The radiographic and visual inspection did not disclose any abnormalities.

3.2.2 Sea Level Spin Firing at 75°F and 30 rpm. Motor assembly S/N 2501-01 with modified nozzle assembly S/N 30205 and igniter S/N 18 was instrumented with thermocouples in accordance with the test plan (see Appendix B). The motor was mounted in a horizontal spin test stand and instrumented for igniter chamber pressure, motor chamber pressure, motor axial thrust, and motor spin rate. The motor was temperature conditioned to 75°F for 43 hours before motor ignition. Figures 1 and 2 present photographs of the test arrangement.

The 30 rpm motor spin rate was maintained for approximately 60 seconds after motor operation and thermocouple data was measured for approximately 550 seconds. NASA Langley Research Center provided thermovision equipment and personnel to conduct thermovision coverage of the nozzle and aft dome during motor operation.

3.3 Motor Performance, Altair III Motor

A post-test evaluation of the measured data, motion picture film, and fired motor components indicated that the motor performed satisfactorily. However, approximately 5 pounds of aluminum slag were retained (normally less than 1/2 pound) in the motor after test (see Figure 3). This was unexpected even though the companion motor tested at AEDC had shown the same phenomenon. At the time of the AEDC test, the abnormal amount of slag retained was attributed to the spin environment. It now appears that the slag retained is also a function of the oxidizer bimodal.

The sea level ballistic performance of Altair III test motor S/N 2501-01 indicates performance equivalent to other Altair III motors tested at sea level. Case and nozzle temperatures during and after firing were all within specification. The firing test data summary is included in Appendix C.

3.3.1 Nozzle Insert Performance. The test data and visual inspection of the post-test nozzle indicate that the insert performance was acceptable. The throat erosion of the insert was comparable to, or slightly less than, previous successful tests with Graph-I-Tite G-90 insert material, as shown in the following table.

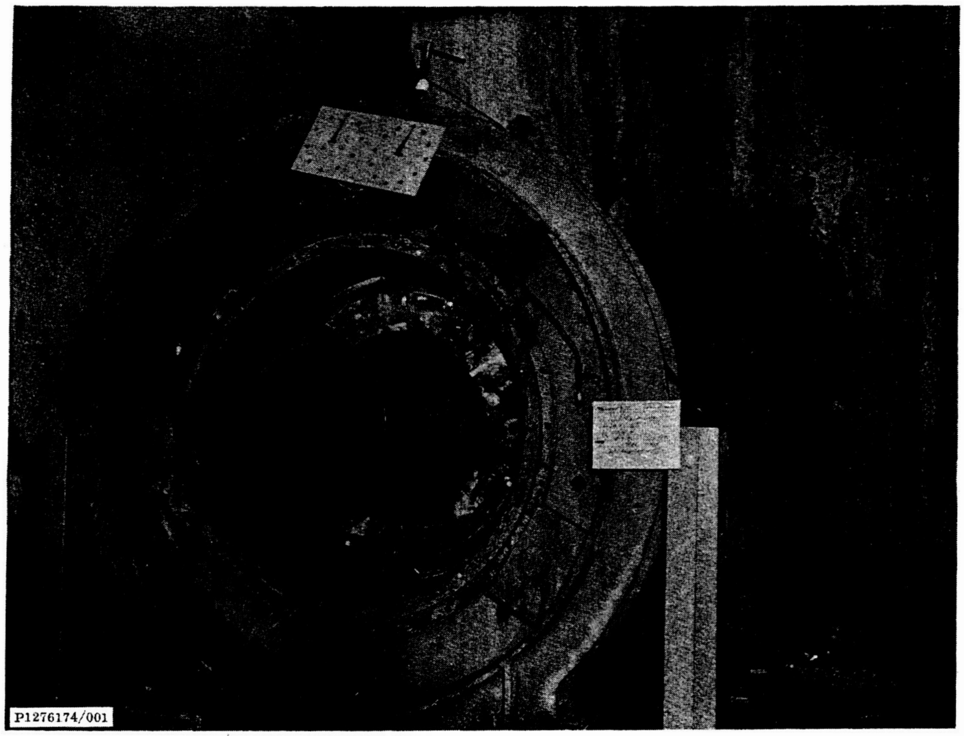


FIGURE 1. ALTAIR III MOTOR PRETEST ARRANGEMENT - NOZZLE END

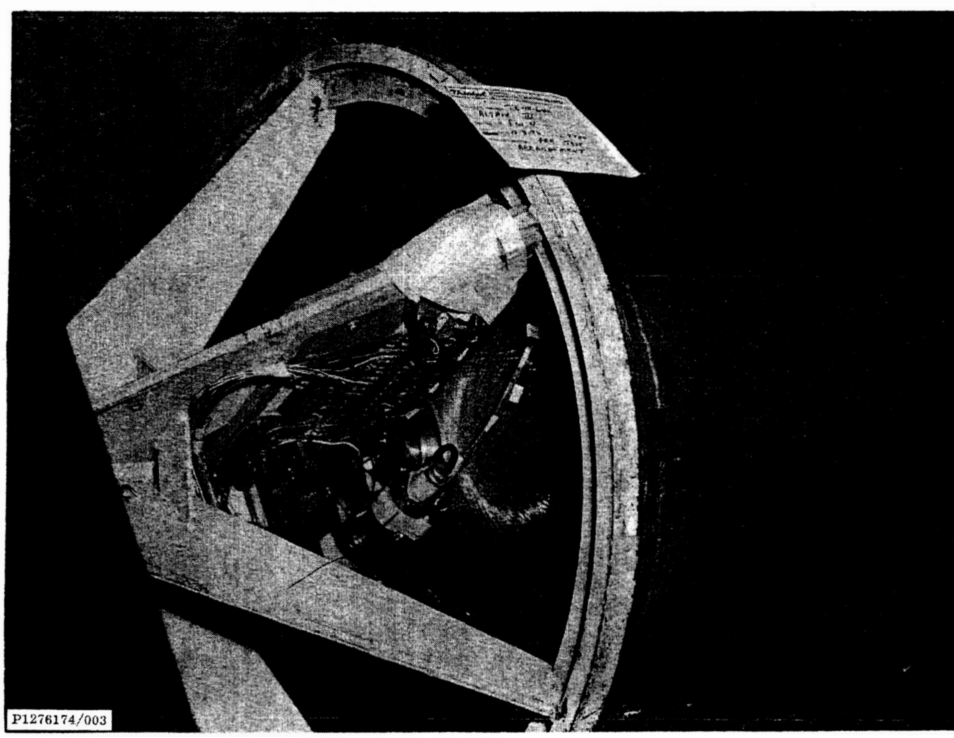


FIGURE 2. ALTAIR III MOTOR PRETEST ARRANGEMENT - HEAD END

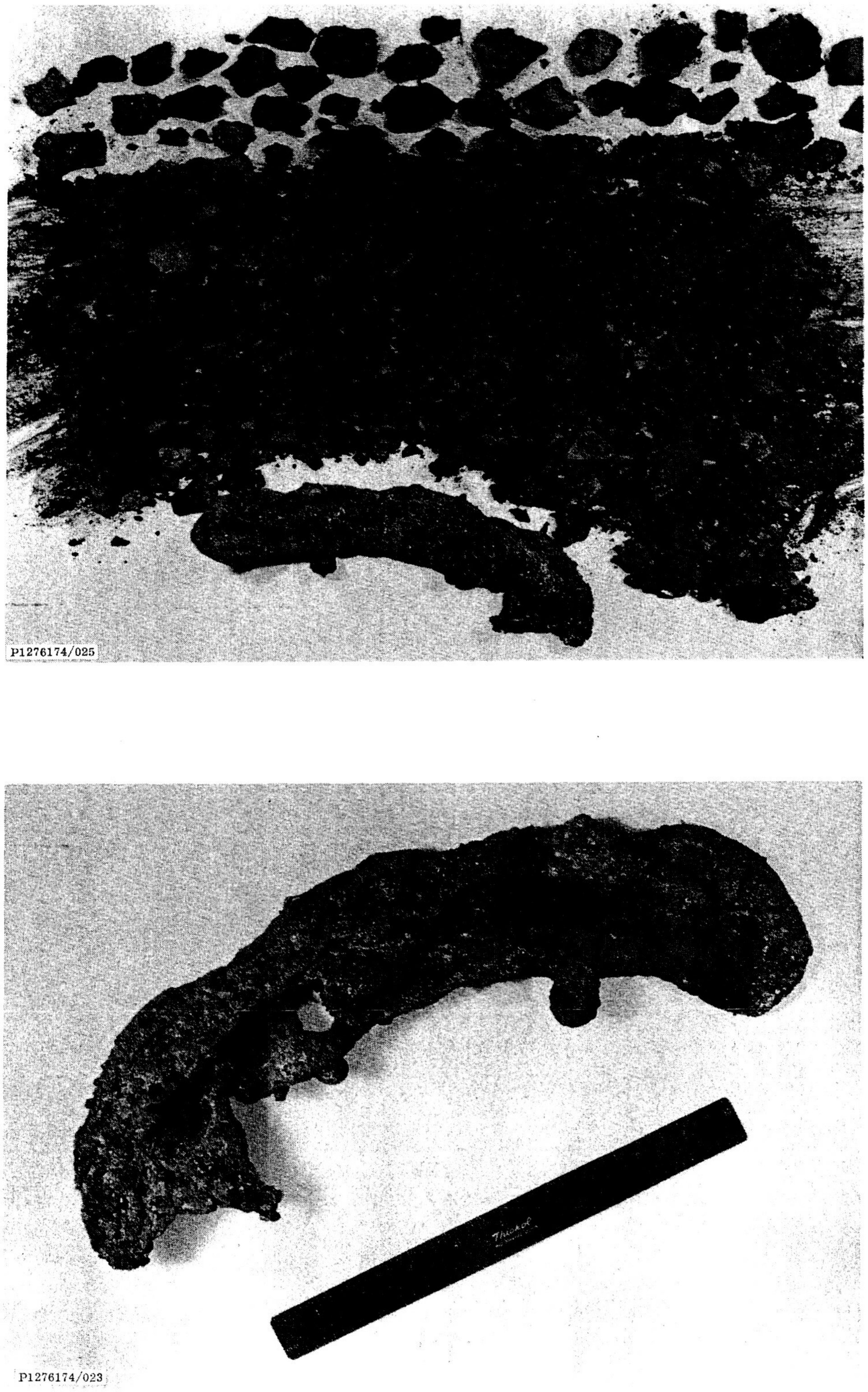


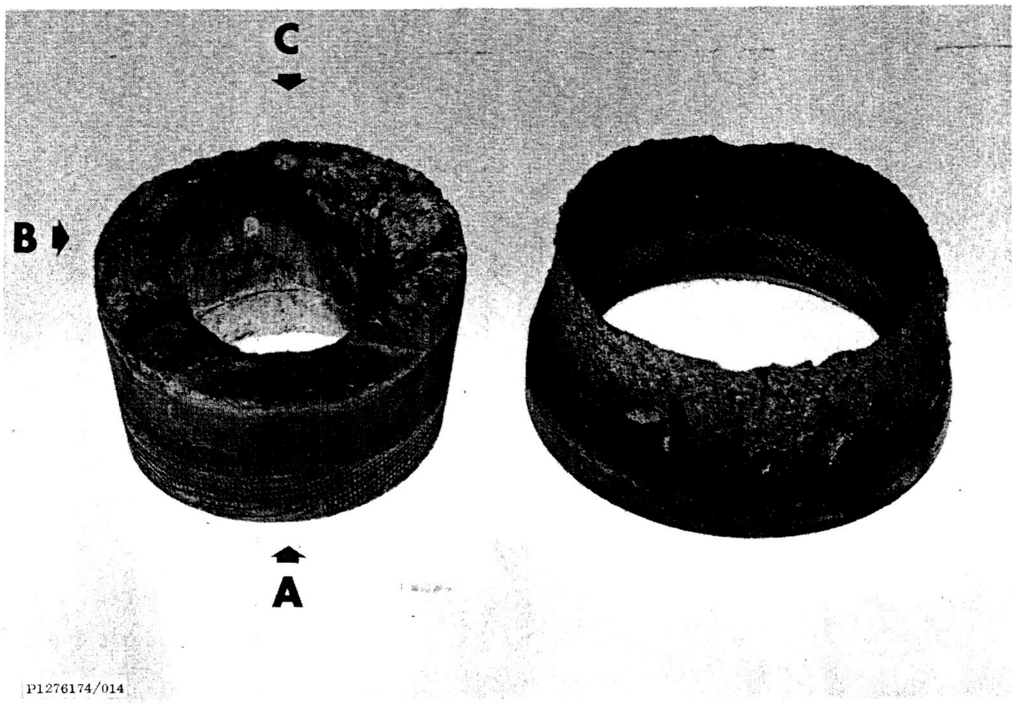
FIGURE 3. ALUMINUM SLAG

THROAT EROSION

Altair Motor	Throat Diameter, in. Before Test	After Test	Throat Area Increase, %	Erosion, mil/sec	Throat Material
Demonstration (PV32-160-1)	2.332	2.524	17	3.2	G-90
PQ-2 (PV32-	2.334	2.510	15.6	2.9	G-90
SQ-1 (PV32-	2.333	2.500	14.8	2.8	G-90
S/N 2501-01	2.335	2.450	10.1	1.9	Tantalum Carbide

Although the throat erosion compared favorably with erosion when G-90 was used, other aspects of the tantalum carbide insert were not as good. Figures 4 through 8 show that the entrance section of the insert was badly eroded and that the insert was severely cracked. The entrance erosion could cause performance losses due to turbulent entrance conditions. As shown in Figures 5, 6, and 7, the backup material is completely gone for about one-third of the insert length, and about one-half its normal thickness is gone for the second third of its length. It is not known whether the loss of the backup ring can be attributed to the nozzle insert (higher heat transfer, entrance erosion, etc), the age of the nozzle (possibility of an inferior carbon phenolic part), or the corrosive effect of the propellant (slag formation). Close observation of the fired insert also disclosed a pockmarking effect and some indications of melting. This is probably due to the nonhomogeneity of the molded insert. The nozzle insert was sectioned along the points A, B, and C as shown in Figure 4. The quarter section between A and B was sent to Vought; the half section between A and C was sent to NASA, and the quarter section between B and C was retained by Thiokol. This sectioning permitted evaluation of overall inlet and outlet erosion patterns of the nozzle insert and adjacent components. Figures 5, 6, and 7 show the sectioned nozzle and insert.

Thiokol conducted a computerized backfitting of the throat diameter utilizing the measured values of chamber pressure and thrust. This backfit process leads to a calculated throat area versus burn time which can be compared against that normally experienced with Graph-I-Tite G-90. The backfit plot of throat area versus time is shown in Figure 9 and appears similar to other Altair tests.



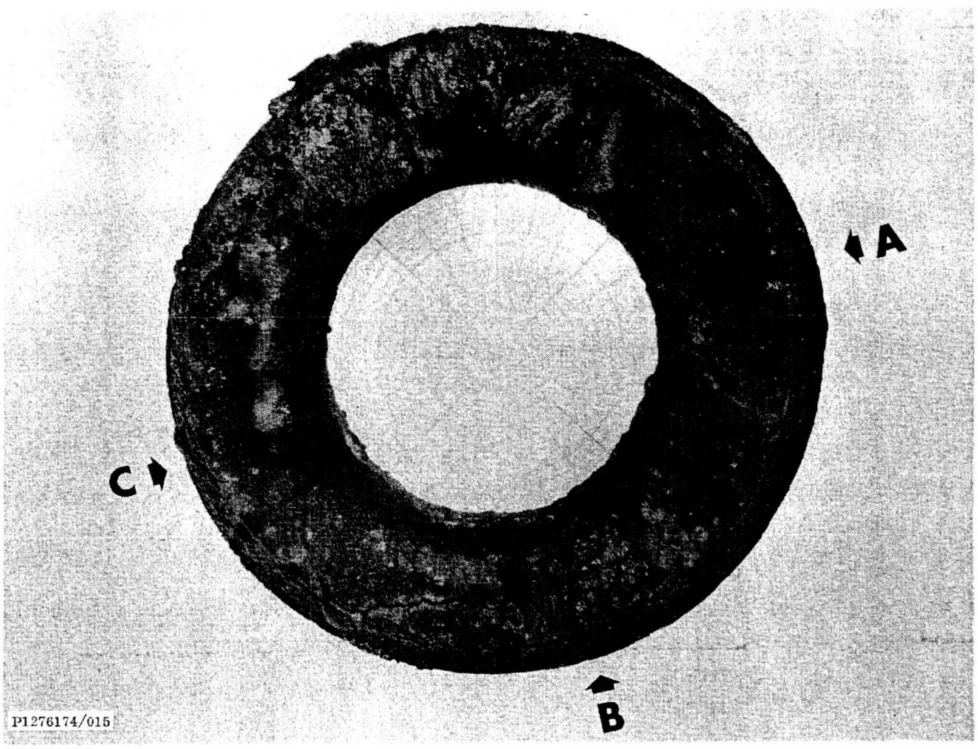


FIGURE 4. ALTAIR III NOZZLE AFTER TEST

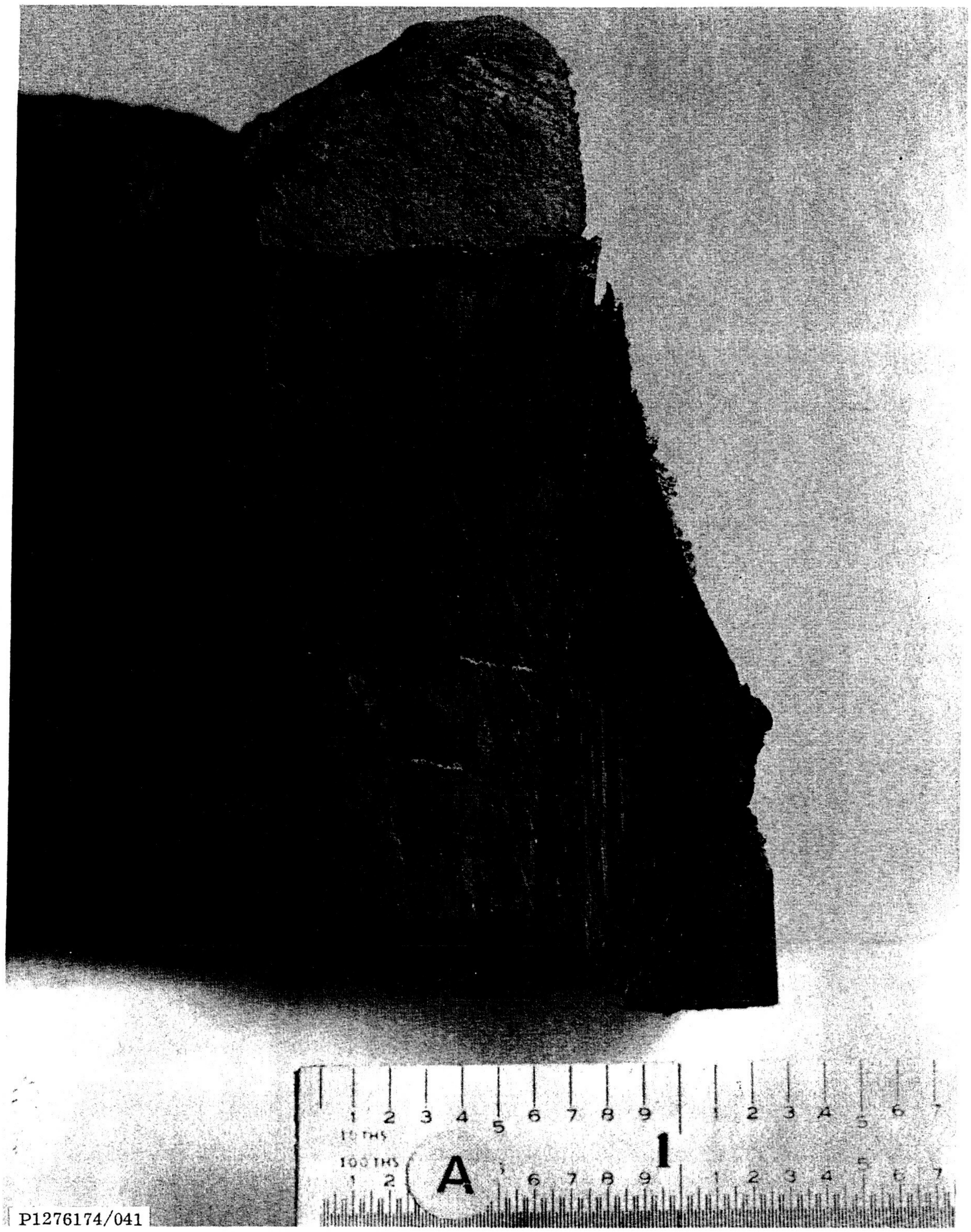


FIGURE 5. SECTIONED NOZZLE, PLANE A

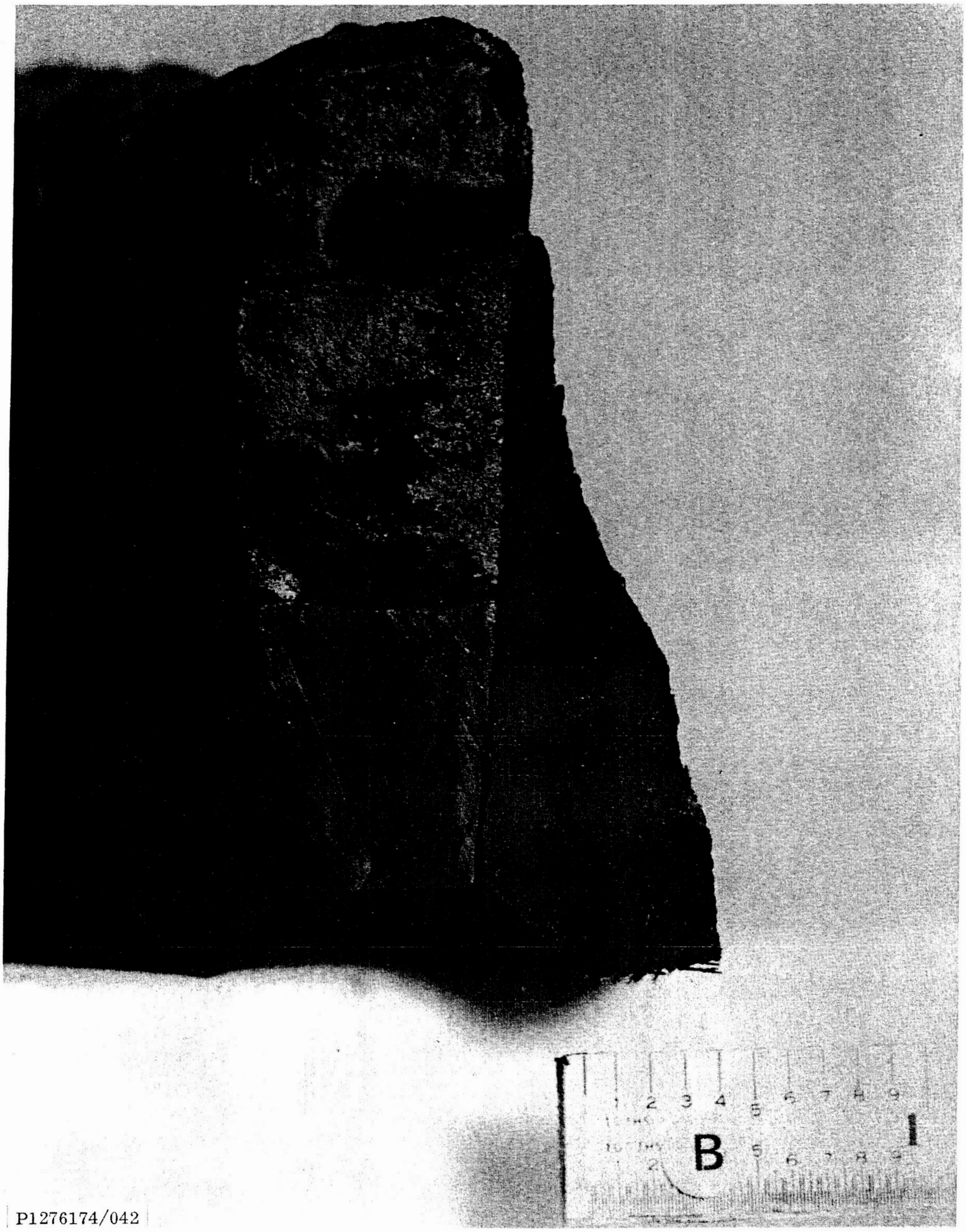


FIGURE 6. SECTIONED NOZZLE, PLANE B

FIGURE 7. SECTIONED NOZZLE, PLANE C

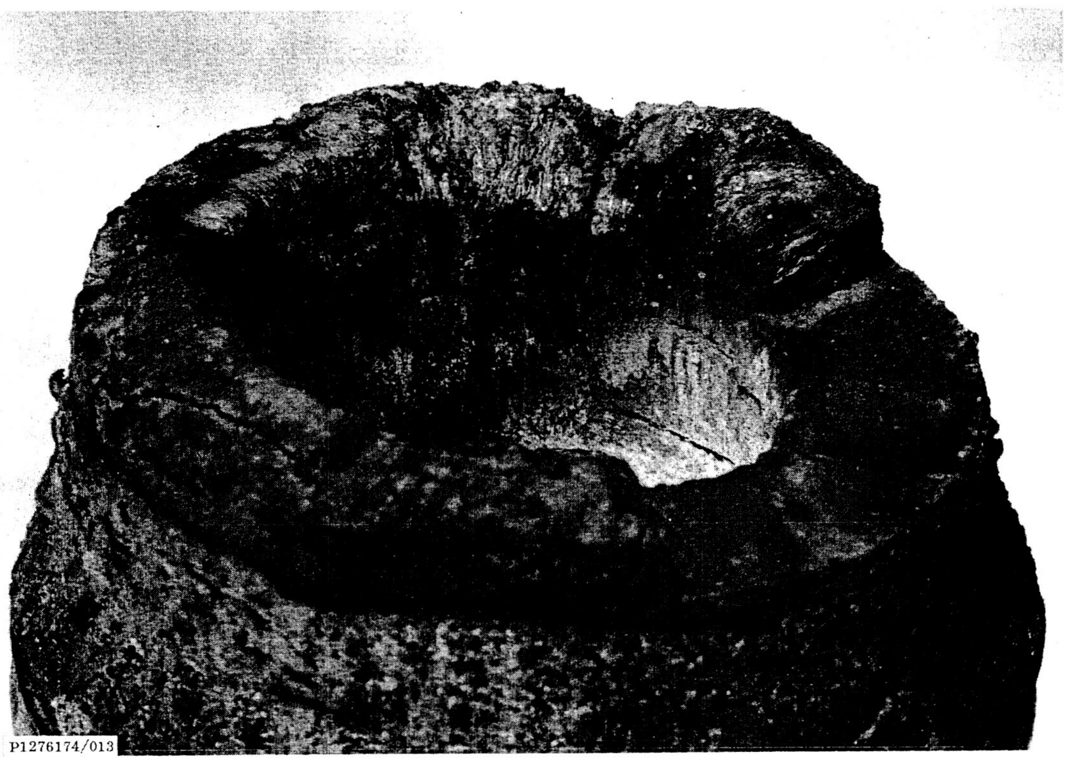


FIGURE 8. NOZZLE INSERT AFTER TEST

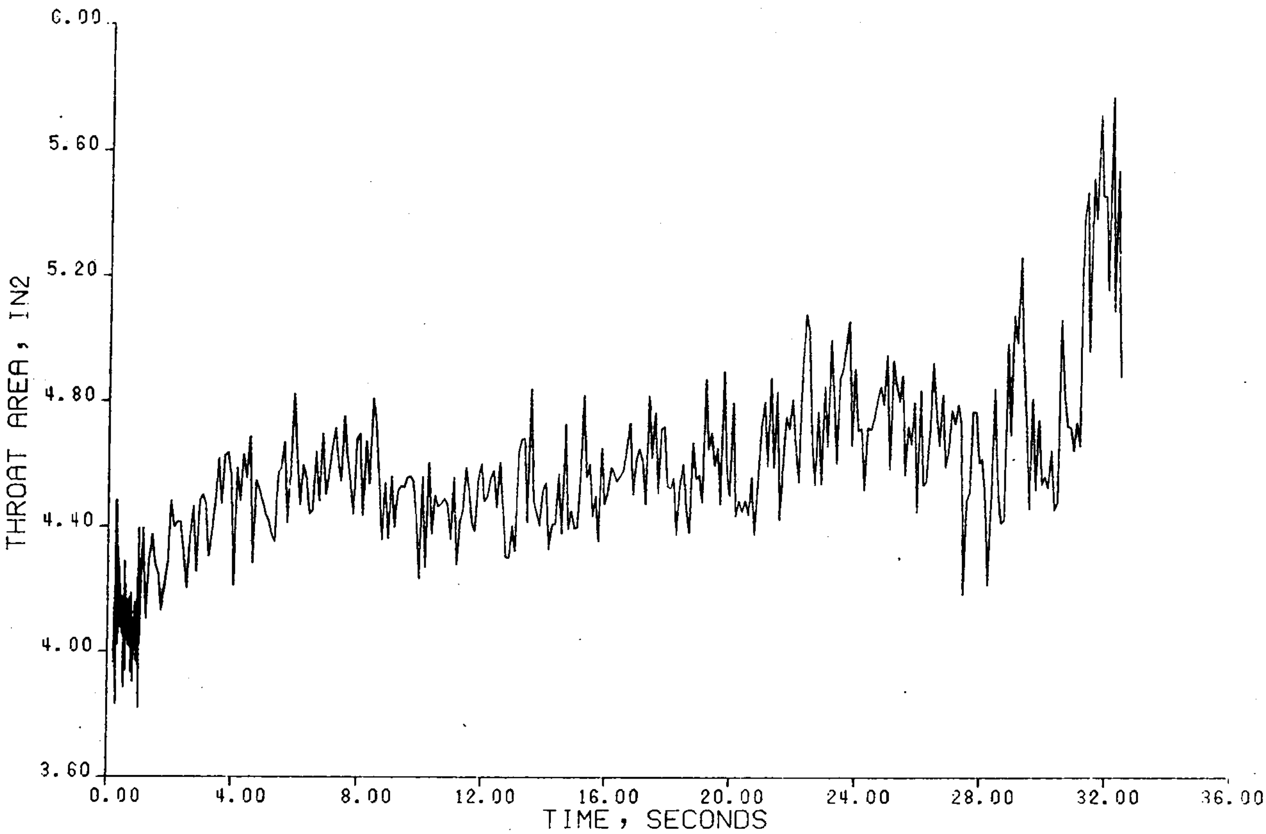


FIGURE 9. ALTAIR III BACKFIT THROAT AREA VS TIME

3.4 Test Configuration, 1000-pound Motor

The 1000-pound test motor is an elongated spherical rocket motor designed for use as an apogee motor. This flightweight solid propellant rocket motor is approximately 30 inches in diameter with an overall length of 57 inches. The loaded case assembly was manufactured by Elkton in December 1975. The loaded case assembly (E28683-02) had 1020 pounds of Thiokol TP-H-3363A propellant from batch PV16-1386. The propellant is a high energy formulation containing 89.7% total solids consisting of 55.5% AP, 16.2% HMX, and 18.0% aluminum, and 10.3% HTPB polymer. The throat insert was made in the same manner as the insert used on the Altair III motor by Los Alamos to a configuration provided by Thiokol drawing LO4935B (Figure 10). When the insert was received at Elkton, the G-90 insert in the Thiokol nozzle (LO4935B) was machined out and the Los Alamos insert installed per a procedure approved by NASA (see Appendix D). Since the motor had a sea level exit cone, a heat shield and a thick layer of a Thiokol mastic insulation, TI-P-304, were placed over the aft dome of the motor case and aft bulkhead to protect these components from external radiant heating. Because of this and the sea level cone, thermovision coverage was not provided during this test. The igniter for the motor was a Thiokol standard control motor igniter consisting of a charge of boron/potassium nitrate pellets and an electrical initiator. The test motor conformed to Thiokol P/N E29438-01. The predicted motor burn time was 59 seconds. The propellant flame temperature was 6055°F.

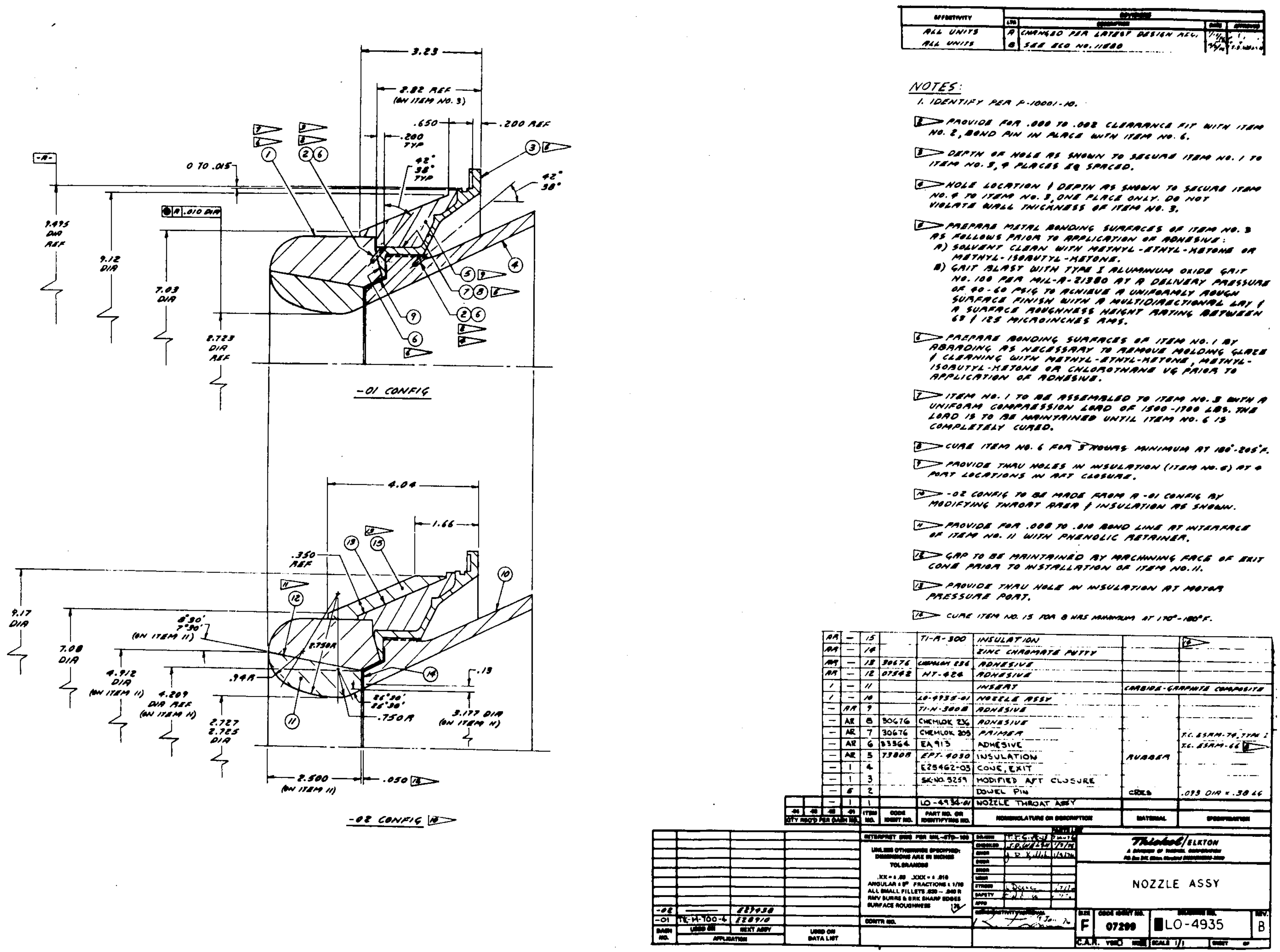


FIGURE 10. THROAT INSERT

3.5 Motor Test, 1000-pound Motor

3.5.1 Pretest Inspection. The 1000-pound test motor has a boot at the aft end. X-ray examination of the loaded case disclosed a separation at the terminus of this boot. The separation was approximately 2 inches long and extended circumferentially all around the motor. Engineering analysis of the separation indicated that it would not be detrimental to the performance of the motor. Post-test review of the data and hardware confirmed the Engineering conclusion. The effect of the separation (additional burning surface) is evident in the pressure time-trace (Appendix F) by the increase in pressure at approximately 34 seconds.

3.5.2 Sea-Level Spin Firing at 75°F and 30 rpm. The motor assembly with modified nozzle assembly was instrumented with thermocouples in accordance with the test plan (see Appendix E). The motor was mounted in a horizontal spin test stand and instrumented for igniter chamber pressure, motor chamber pressure, motor axial thrust, and motor spin rate. The motor was temperature conditioned to 75°F before motor ignition. Figures 11 and 12 present photographs of the test arrangement. The 30 rpm motor spin rate was maintained for approximately 60 seconds after motor operation and thermocouple data was measured for approximately 200 seconds. Since the aft dome of the motor case and aft bulkhead down to the bulkhead nozzle exit cone interface were coated with insulation to protect these components from radiant heating during motor operation, thermovision coverage of the nozzle and aft dome was not possible.

3.6 Motor Performance, 1000-pound Motor

A post-test evaluation of the measured data, motion picture film, and fired motor components indicate that the motor performed satisfactorily. The sea-level ballistic performance was equivalent to other Thiokol 30-inch motors. The firing test data summary is included in Appendix F.

3.6.1 Nozzle Insert Performance. The test data and visual inspection of the post-test nozzle indicate that the insert performance was acceptable. Figure 13 shows the general condition of the post-test insert. Although the nozzle throat erosion was equivalent to erosion using G-90, there was severe erosion and melting in the entrance section and cracks in the insert material were noted. The performance of this insert was almost identical to the one tested in the Altair III motor except that the carbon phenolic throat backup was not as severely eroded, as shown in Figure 14.

Thiokol conducted a computerized backfitting of this throat insert diameter, also utilizing the measured values of chamber pressure and thrust. The backfit plot of throat area versus time is shown in Figure 15. As can be seen from this figure, the throat erosion rate increased in the latter half of the motor burn, but the average

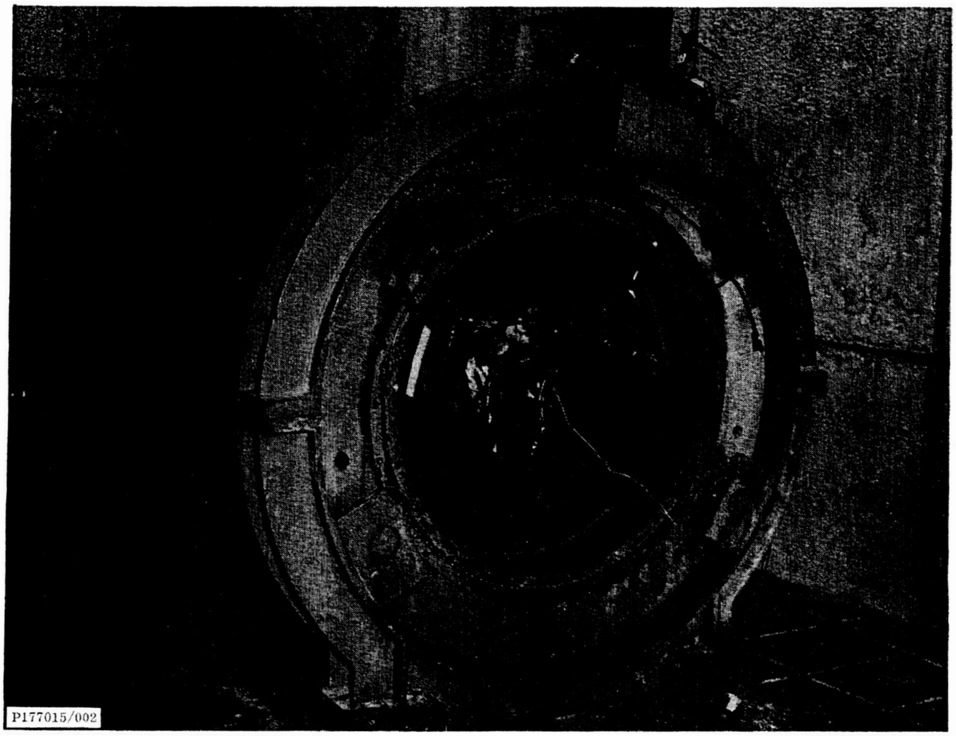


FIGURE 11. NOZZLE END OF 1000-POUND MOTOR BEFORE TEST

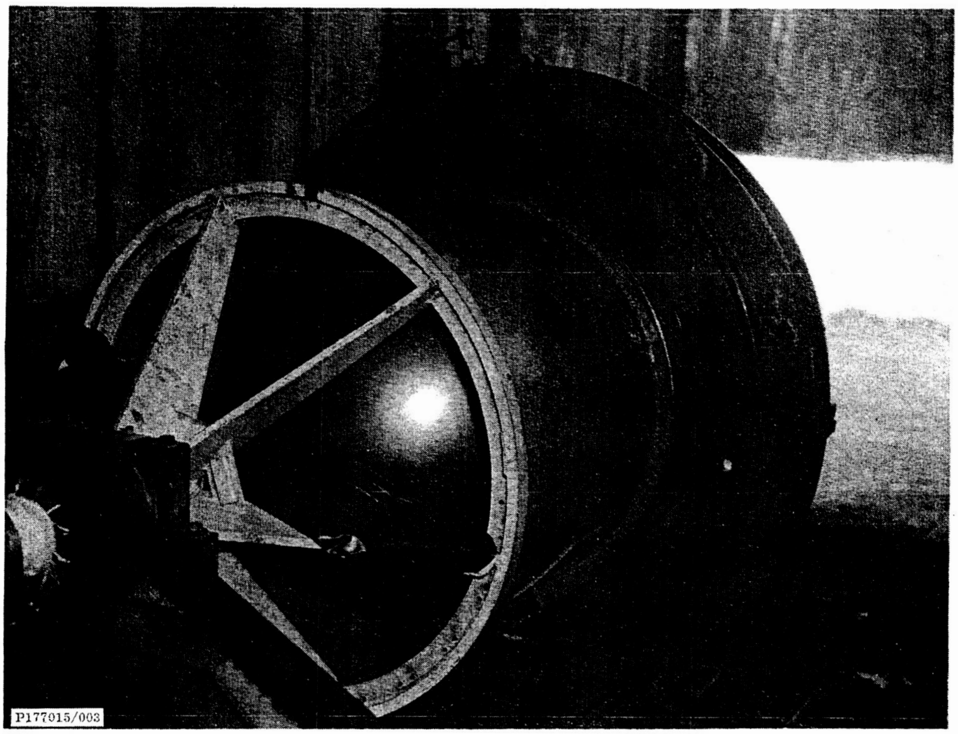
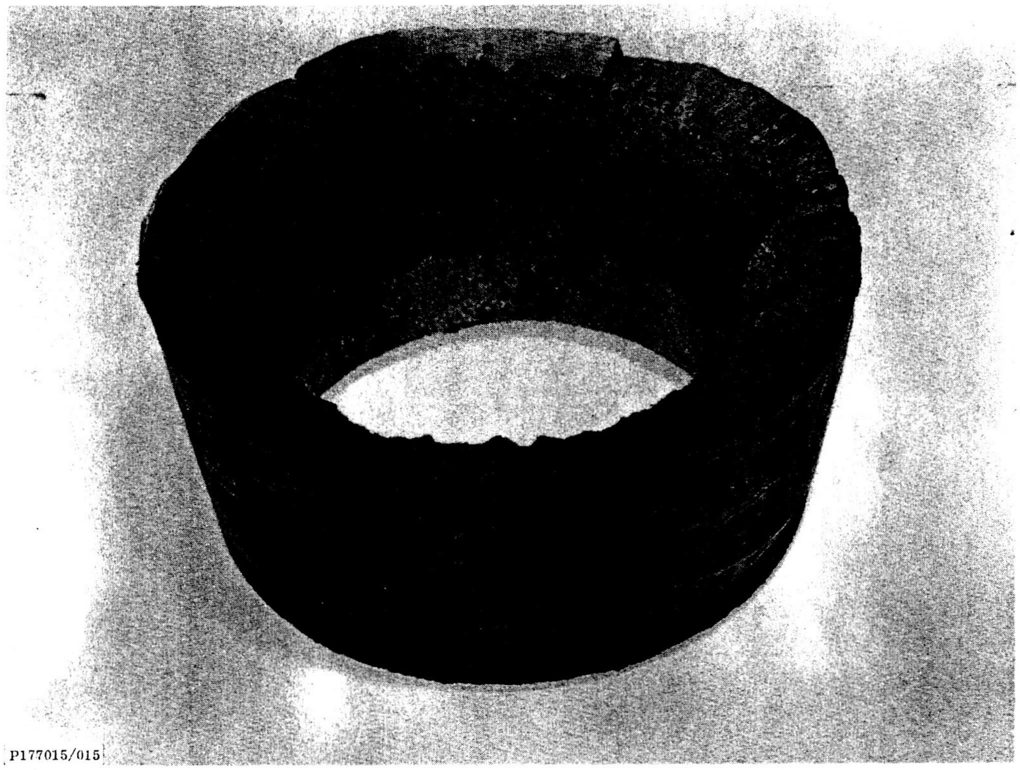


FIGURE 12. HEAD END OF 1000-POUND MOTOR BEFORE TEST



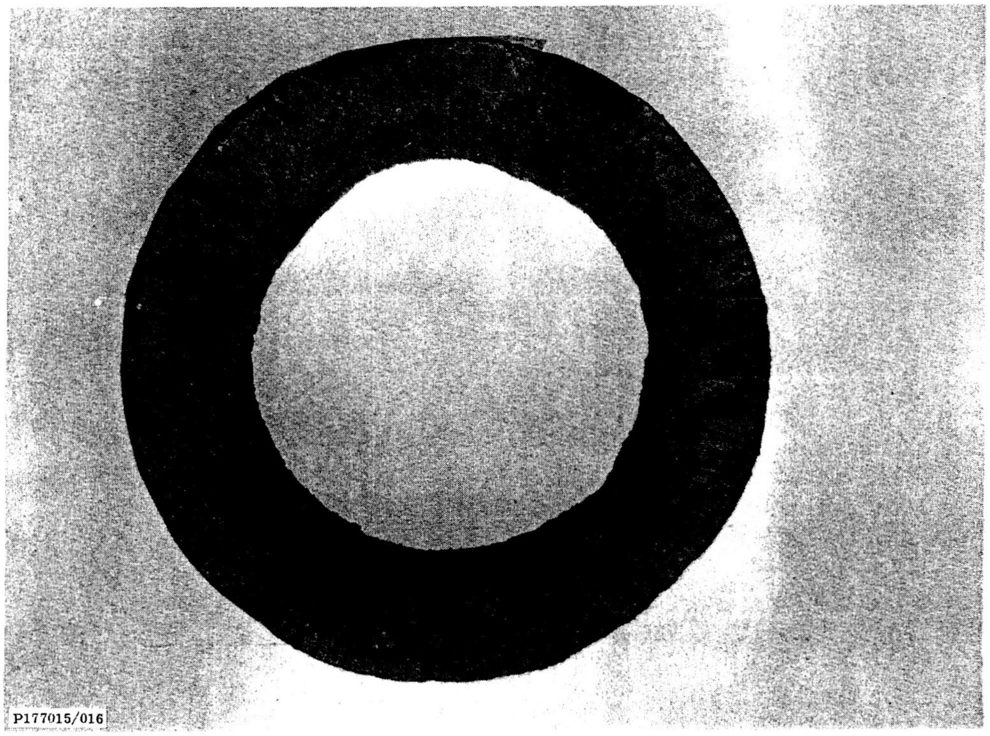


FIGURE 13. NOZZLE FROM 1000-POUND MOTOR AFTER TEST
(Clear tape was placed around insert to retain shape.)

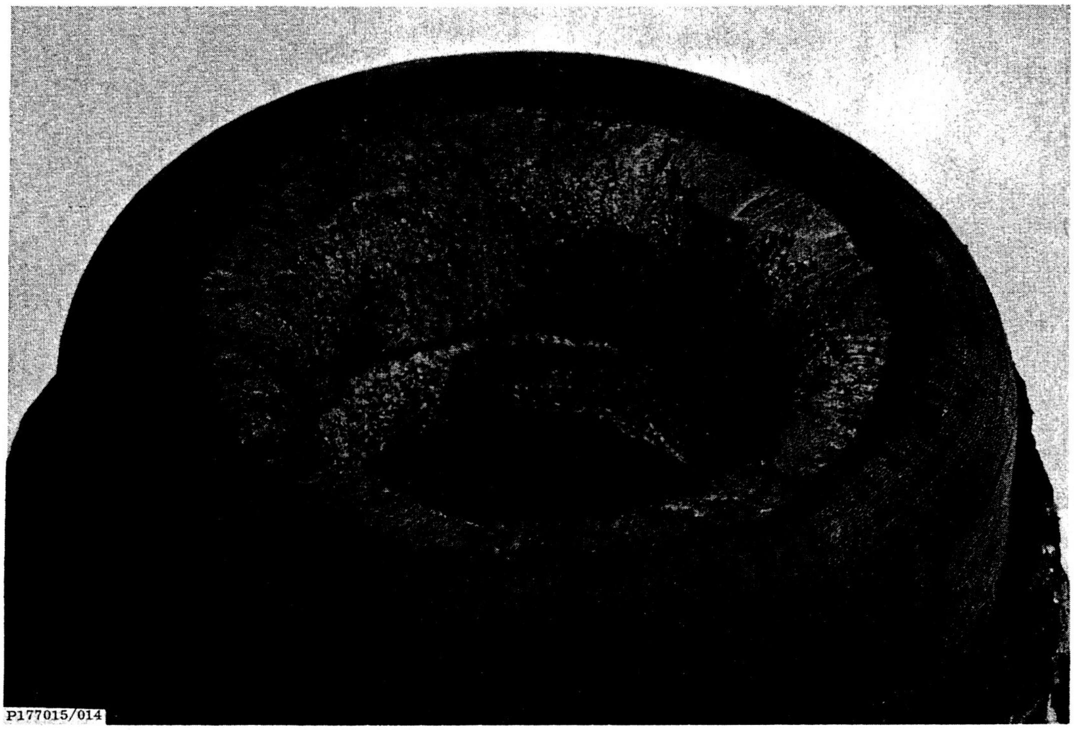


FIGURE 14. NOZZLE FROM 1000-POUND MOTOR AFTER TEST

erosion rate of 3.2 mil/sec compares very favorably with the carbide insert tested in the Altair motor and with G-90 tested in other 30-inch, 1000-pound test motors. The sharp increase in erosion rate during the latter 30 seconds of burn indicates that the insert may be plastic and could indicate unsatisfactory performance in long burn time motors.

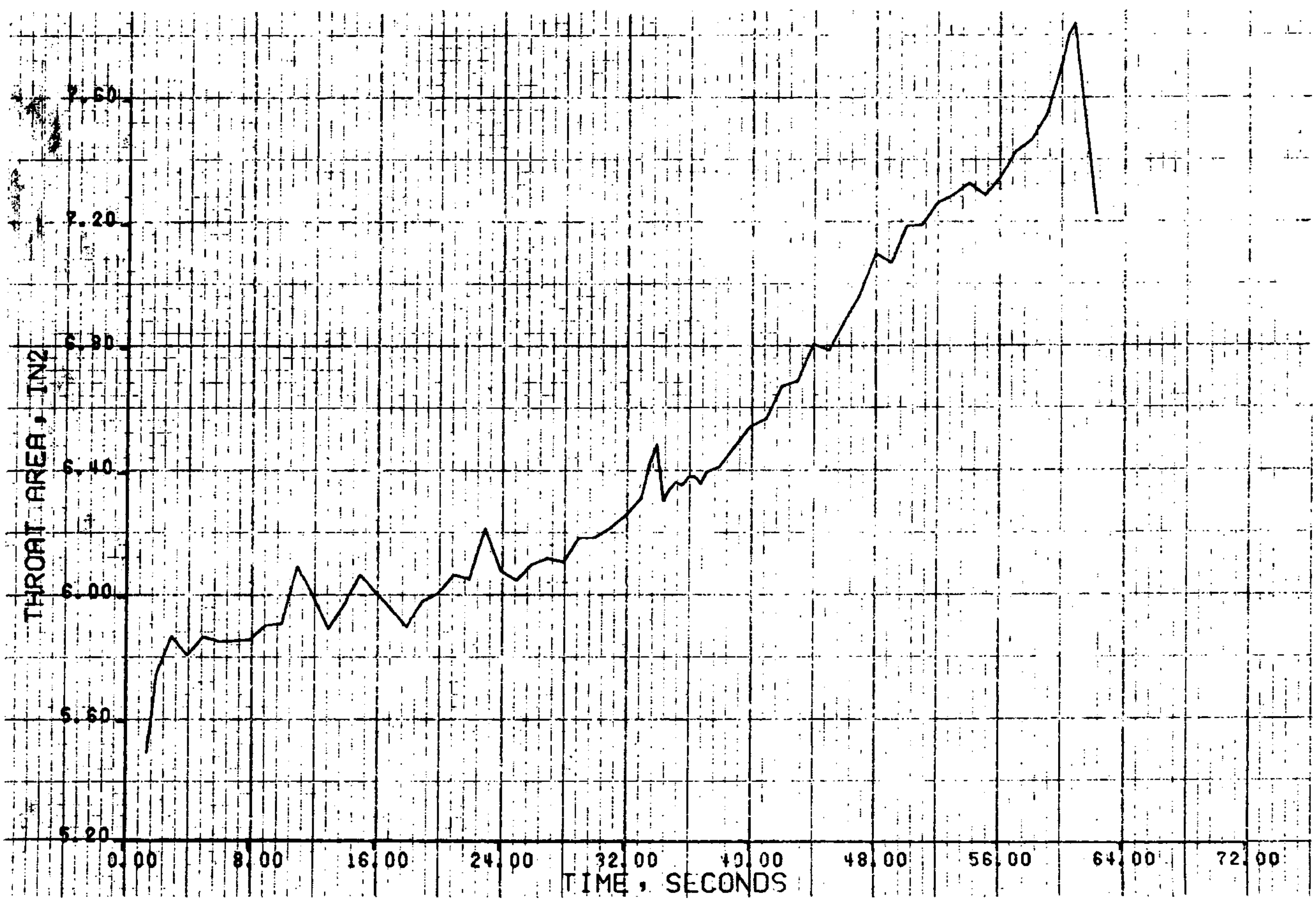


FIGURE 15. 1000-POUND MOTOR THROAT AREA VS TIME

APPENDIX A

PROCEDURE FOR

REPLACEMENT OF NOZZLE THROAT INSERT, ALTAIR III
VOUGHT DRAWING: 23-427002, REVISION A

THIOKOL CORPORATION
ELKTON DIVISION
ELKTON, MARYLAND

PROCEDURE

REPLACEMENT OF NOZZLE THROAT INSERT, ALTAIR III
VOUGHT DRAWING: 23-427002 REV. A

Prepared By: E. [illegible] Guerber Date: 11/24/76
Manufacturing Engineer

Approved By: [illegible] Date: [illegible]
Rocket Engineer

Approved By: S Kanle Date: 11/24/76
Program Manager

The following procedure details the operations to be completed to replace the existing throat insert of an Altair III nozzle with a new configuration. This new configuration is a carbide-graphite insert supplied by Los Alamos Scientific Lab of the University of California.

1. Manufacture lathe fixture piloting on the 5.185/5.182 diameter, interfacing with mounting face of the flange and to hold nozzle exit plane against lathe face plate.

2. Position and clamp nozzle assembly in lathe fixture and clamp to lathe face plate. Indicate 2.334 diameter (throat diameter) within .002 TIR and face of flange for best position shimming as required at aft exit plane of nozzle assembly.

3. Withdraw from stores finish machined carbide-graphite throat insert to be substituted for G-90 throat insert, measure 7° 57' to 8° 3' angle and maximum diameter as shown on Drawing 23-427026.

   Angle __________ Diameter __________

4. Machine out G-90 throat insert in nozzle by machining at angle measured on carbide-graphite insert in Step 3. Machine until diameter at forward face of angle (largest diameter) is $\substack{.022 \\ .018}$ greater than diameter measured in Step 3 on carbide-graphite insert.

   NOTE: Do not remove material from exit cone.

5. Dry fit carbide-graphite throat insert for bondline thickness. Shim between exit cone forward face and aft throat insert face until shim is .010 to .038 thick and bondline gap is .008 to .012. Measure bondline gap using machinist clay at 3 locations.

   Bond Gap __________ Shim Thickness __________

   NOTE: Parts and adhesive shall be handled using clean white gloves during cleaning, adhesive application and assembly for cure.

6. Surface preparation and bonding. Wipe bonding surfaces of throat and throat insulator with MEK. Allow 15 minutes drying time. Hand sand with 40 to 120 grit paper, bonding surfaces of throat and throat insulator until uniformly abraded.

7. Apply zinc chromate putty on forward face of exit cone of thickness equivalent to shim used in Step 5 + .005. Bond surface to be free of zinc chromate putty.

8. Rinse with MEK. Wipe clean with cloth dampened with MEK. Check cloth for contaminants. Air dry 1 hour minimum. Bonding operation shall be performed within 8 hours of grit paper abrading. Cut HT-424 adhesive film on clean wax free paper. Place adhesive film flat on work bench and remove top polyethylene separator. Avoid wrinkling adhesive film. Place graphite throat on adhesive film and carefully wrap film around throat. Do not stretch film. Hold film on throat in place with masking tape at excess areas. Place shim strip under overlapping ends of adhesive film and cut through both layers of film simultaneously to establish a clean butt joint. Remove shim strip and holding film in contact with throat, remove polyethylene separator. Trim off excess adhesive film at both ends. Slip throat carefully on throat insulator without disturbing adhesive film. Place assembly on shop aid plates and torque 1/2 inch nut to 400 inch-pounds.

9. Place nozzle in oven and cure at 230 to 250°F for 12 to 13 hours.

   Cure Temperature ________ °F Cure Time ________ hours

10. Remove zinc chromate putty in gap between throat insert and exit cone for a depth of 0.13 ± .03 per Drawing 23-427002.

11. Deliver nozzle to Quality Control for following inspection:

    A. Perform alcohol wipe test of carbide-graphite throat and all exposed surfaces on plastic parts. Cracks of any size shall be cause for rejection.

       Accept __________ Reject ________ ER No. __________

    B. X-ray nozzle for defects with a minimum of 6 tangential views of throat insert to measure bond gap. Provide film to Engineering for evaluation.

APPENDIX B

TEST PLAN,
STATIC TEST OF ALTAIR III ROCKET MOTOR
(S/N 2501-01)

THIOKOL CORPORATION
ELKTON DIVISION
ELKTON, MARYLAND

TEST PLAN

STATIC TEST OF ALTAIR III ROCKET MOTOR
(S/N 2501-01)

Prepared By: ______________________ Date: 24 Nov 76
Project Engineer

Approved By: ______________________ Date: 11/24/76
Rocket Engineer

Approved By: ______________________ Date: 12/3/76
Program Manager

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1.0 INTRODUCTION

This test plan details the requirements for the test of an Altair III Rocket Motor (S/N 2501-01).

2.0 SCOPE

2.1 This plan describes in detail the sea level test of the Altair III motor (S/N 2501-01).

3.0 TEST OBJECTIVES

3.1 The primary purpose of the static test is to evaluate the performance of a new nozzle insert configuration in an Altair III motor when fired at 30 ± 5 RPM and 75° +5°F. A secondary purpose of the test is to validate the igniter performance of an "aged" igniter assembly manufactured by Thiokol.

3.2 The motor shall be static tested after temperature conditioning at 75 ± 5°F for 44 hours minimum. The motor shall be tested while spinning at 30 ± 5 RPM under sea level conditions. Spin direction shall be counter clockwise as viewed from the nozzle end of the rocket motor.

4.0 TEST ARTICLE DESCRIPTION

4.1 The Altair III rocket motor is the standard fourth stage propulsion unit for the Scout Launch Vehicle. The flight-weight solid propellant rocket motor is approximately 19-1/2 inches in diameter with an overall length of 58-1/2 inches. The case is a filament-wound glass fiber and epoxy resin structure which incorporates high strength aluminum polar bosses for igniter and nozzle installation. The nozzle configuration being evaluated utilizes a carbide-graphite composite throat insert in place of the standard Graphitite G-90 insert and the standard expansion cone structure of carbon phenolic and graphite cloth bonded to the carbon phenolic from the insert to an area ratio of 50:1. The cone is backed with a steel shell to provide structural rigidity. The motor and nozzle are government furnished components. Individual components will have been subjected to visual, dimensional, radiographic, and leak test inspections prior to test.

Prior to testing, the "as received" nozzles' Graphitite G-90 throat insert will be machined out and replaced with a carbide-graphite composite insert supplied by NASA. This operation will be completed using a Thiokol prepared Scout Project Office (SPO) approved procedure.

4.2 The TE-P-648-1 (S/N 18) igniter utilizes Thiokol-manufactured hardware loaded with Thiokol TP-H-3062 propellant system. Two initiators are normally used to ignite the igniter; however, since a measurement of the igniter chamber pressure is needed, a single SBASI initiator will be used for ignition and the spare port used for pressure measurement. The SBASI does not have an ignition delay. The igniter is supplied by G.F.E. and was selected to obtain shelf life evaluation data.

5.0 TEST DESCRIPTION

5.1 Static Test - Altair III

5.1.1 The Altair III rocket motor assembled in accordance with Thiokol Drawing E29436-01, with igniter in place, shall be subjected to testing in accordance with the following plan.

5.1.1.1 General handling and storage of the motor shall be accomplished using slings, hoists, and the 7001-034 handling dolly.

5.1.2 The rocket motor of 5.1.1 shall be assembled in its test arrangement as described by (marked-up) Thiokol Drawing E25794 and temperature conditioned at 75° ± 5°F for 44 hours minimum, then fired at sea level pressure while spinning about its axial center line at 30 RPM. Spin direction shall be counter clockwise as viewed from the nozzle end of the rocket motor. A single SBASI initiator shall be used to accomplish ignition.

5.1.3 Prior to assembly in the test arrangement, thermocouples will be installed on the assembly at locations as shown in Figure 1.

5.1.4 Data acquisition shall consist of measurements of motor chamber pressure, igniter chamber pressure (as measured through the unused initiator port), spin rate, external case and nozzle temperatures, and thrust. The spin rate shall be maintained for t_o + 60 seconds and temperatures should be monitored through to +500 seconds. The parameters shall be recorded as indicated on Table I of this plan. The motor shall be quenched with dry powder within approximately 60 seconds of the completion of propellant burning and a smother cover shall be installed over the nozzle exit plane as soon as possible after the motor has stopped spinning to prevent insulation burnout.

5.1.5 Ballistic data presentation shall consist of plots versus time of pressures, temperature, spin rate, and measured thrust. Integrals and other data parameters as defined by the Altair Model Specification, TEMS-25, shall be determined and presented in suitable data summary form.

5.1.6 Physical measurements of pre and post-test nozzle throat and exit diameters (at 30° intervals) shall be recorded as well as pre and post-test weights of the motor assembly and components. The hardware, particularly the nozzle components, will be studied after testing by techniques to be agreed upon with the Scout Project Office (SPO).

5.1.7 Still photographs of the pre and post-test motor assembly and test arrangement shall be made in detail as necessary.

5.1.8 One standard speed motor camera will be positioned to view the overall static test. Two high-speed cameras will be positioned on either side of the test bay for coverage during action time of the motor. A marking strip shall be located on the motor case in view of the cameras for use as a visual point of reference. See Figure 2 for schematic of camera locations. A clock with sweep second hand must appear in the camera field of view.

6.0 DATA REDUCTION

6.1 A data summary report of the ballistic results shall be prepared and shall include test date and time, temperature, nozzle dimensions (pre and post), motor weights, propellant weights, pressure and thrust integrals, burn time, action time, ignition delay, characteristic velocity, specific impulse, etc. MDR-T-5138 shall be used for defining the parameters and procedures to be used in data reduction.

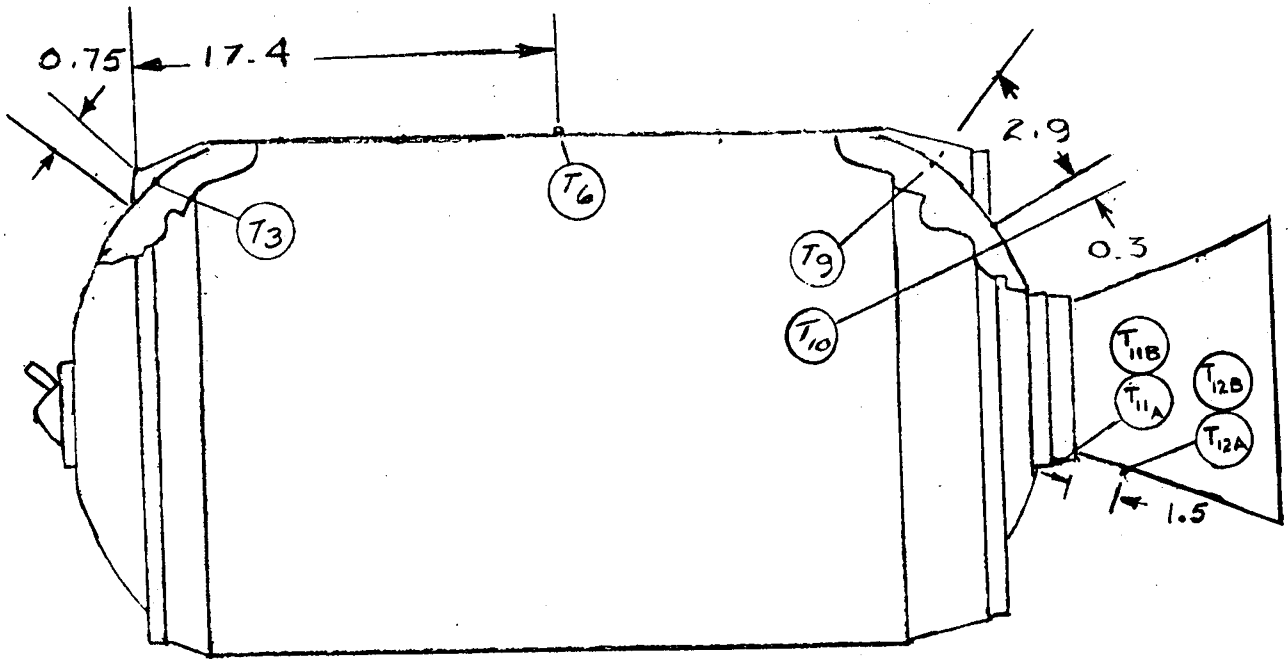


FIGURE 1. INSTRUMENTATION PLAN, ALTAIR III, THERMOCOUPLES

NOTES: 1. Thermocouples 11B and 12B to be located 90° from thermocouples 11A and 12A respectively.

2. Thermocouples 11A and 11B to be located as close to "corner" of aluminum adapter of nozzle as possible.

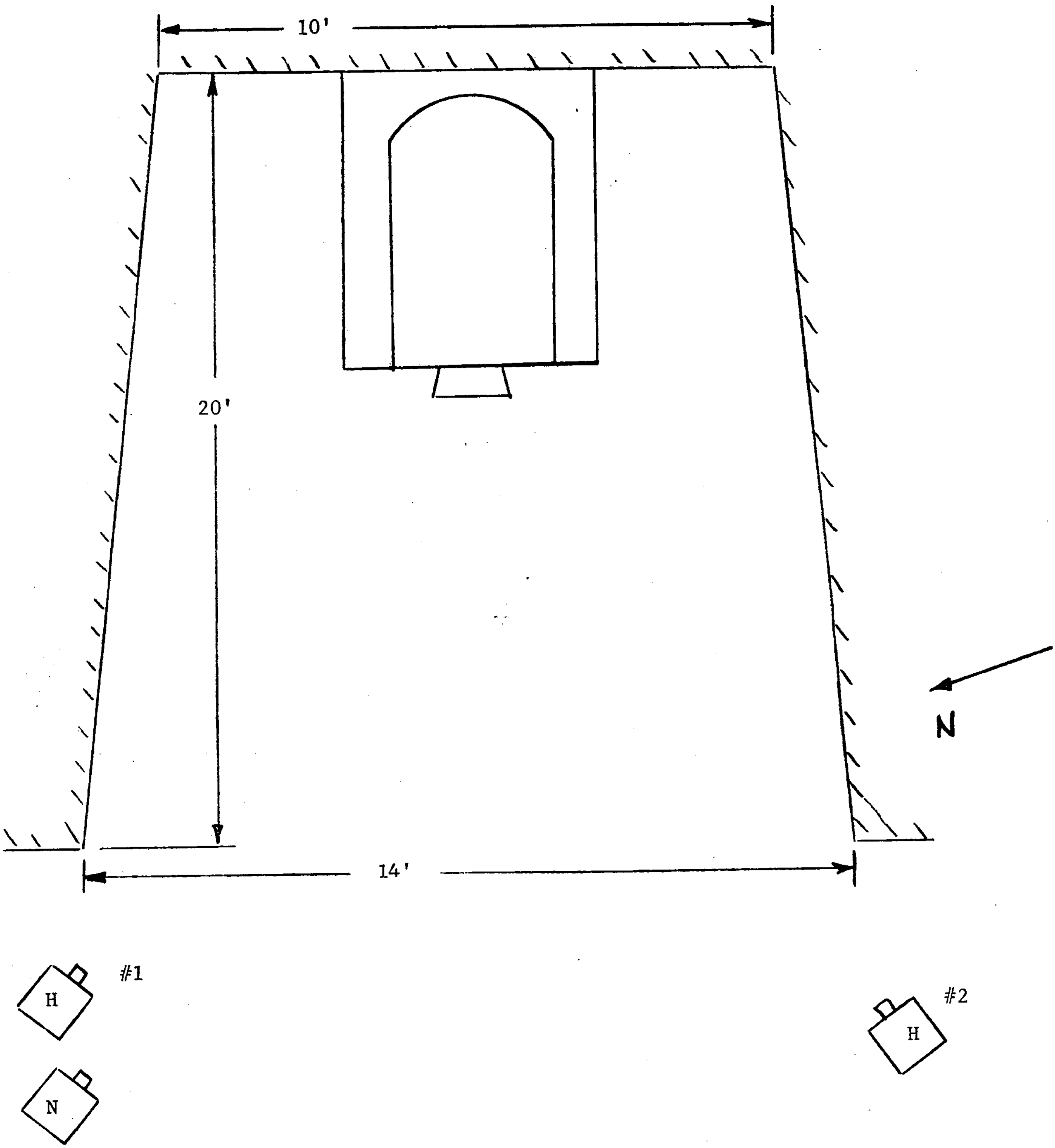


FIGURE 2. CAMERA ARRANGEMENT AND TEST CELL DESCRIPTION

NOTES: 1. N is a standard speed camera.

2. H is a high speed camera (400 fps).

3. Spin stand and motor not to scale.

TABLE I

DATA ACQUISITION

Parameter	CEC	DIDACS	
P_{c_1} & $_2$	#1	1	0-1000 psig, utilize 8 slip rings
Motor Chamber Pressure	#2	13	
P_{P_1} Igniter Pressure			0-3000 psig, utilize 4 slip rings, measured through squib port
F_1 & F_2	#1	15	0-10,000 lbf
Thrust	#2	16	
Temperature T_3, T_6, T_9, T_{10}, T_{11A}, T_{11B}, T_{12A}, T_{12B}	#1		Chromel versus Alumel 1100°F max temperature utilize 16 slip rings
Spin Rate	#1 #2		30 $\pm$ 5 RPM, continue for 1 minute after test
Ignition Current	#1		Provide 6.0 amps min to single squib, utilize 2 slip rings
Zero Time	#1 #2		

NOTE: 1. Total number of slip rings utilized - 30. CEC oscillograph recorder #1 to operate at 10.0 inches per second for about 60 seconds after zero time, then at 1 inch per second up to t_o + 500 seconds. CEC #2 to operate at 10 inches per second through the first 60 seconds after zero time.

2. Thermovision monitoring of the exhaust nozzle to be accomplished by NASA. AC power will be supplied by Thiokol for this equipment.

APPENDIX C

FIRING DATA SUMMARY, FW-4S ROCKET MOTOR

FIRING DATA SUMMARY
FW-4S ROCKET MOTOR

MOTOR IDENTIFICATION

1. Project 2720
2. Motor Part No. UTC-B0686-01-02 Serial No. 2501-1
3. Propellant Grain Batch/Unit No. FW-4S
4. Igniter Part No. E25803-02 Serial No. 18
   Initiator Part No. SEB 26100001-211 Serial No. 895
5. Trace No. S0824

TEST CONDITIONS

1. Test Date 9 Dec. 1976 Test Time 1144
2. Motor Conditioned Temperature +75 ± 5 °F
3. Conditioned 43 hours prior to test
4. Ambient Temperature 36 °F
5. Ambient Pressure at Time of Test, psia sea level
6. Motor tested at Thiokol facility while spinning about the thrust axis at 30 rpm.

   This spin rate was maintained for 60

   seconds after ignition.

PHYSICAL DATA

1. Motor Propellant Type UTC 3096A
2. Igniter Propellant Type TPH 3062
3. Propellant Weight, lb_m Motor N/A

   Igniter N/A

PHYSICAL DATA (continued)

4. Motor Assembled Weight, lb_m	Pre-test	665.80
	Post-test	57.70
5. Measured Nozzle Throat Area, in^2	Pre-test	4.282
	Post-test	4.716
	Average	4.499
6. Measured Nozzle Exit Area, in^2	Pre-test	214.63
	Post-test	216.40
	Average	215.52
7. Average Measured Expansion Ratio		47.90

TIME DATA

1. Initiator Time, td_i, sec	0.010
2. Ignition Delay Time, t_d, sec	0.083
3. Action Time, t_a, sec	32.40
4. Burn Time, t_b, sec	31.08
5. Total Time, t_t, sec	33.50

PRESSURE DATA

1. Maximum Igniter Pressure, P_{ign}, psia	2445
2. Maximum Pressure, P_{max}, psia	795
3. Average Pressure over Burn Time, $\overline{P}_b$, psia	667
4. Average Pressure over Action Time, $\overline{P}_a$, psia	648
5. Pressure-Time Integral over Burn Time, $\int P_c dt_b$, psia-sec	20726

Motor No. 2501-1

PRESSURE DATA (continued)

6. Pressure-Time Integral over Action Time, $\int P_c dt_a$, psia-sec	20980
7. Characteristic Exhaust Velocity, C*, ft/sec	N/A

MEASURED THRUST AND IMPULSE DATA

1. Maximum Thrust, F_{max}, lb_f	4800
2. Average Thrust over Action Time, $\bar{F}a$, lb_f	3923
3. Average Thrust over Burn Time, $\bar{F}_b$, lb_f	4041
4. Burn Time Impulse, $\int F dt_t$, lb_f-sec	125583
5. Total Impulse, $\int F dt_t$, I_t, lb_f-sec	127414
6. Effective Specific Impulse, $Isp_{(eff)}$, lb_f-sec/lb_m	N/A
7. Propellant Specific Impulse, Isp, lb_f-sec/lb_m	N/A
8. Action Time Impulse, $\int F dt_a$, lb -sec	127100

NOTE: Special tantalum/carbide throat insert supplied by NASA.

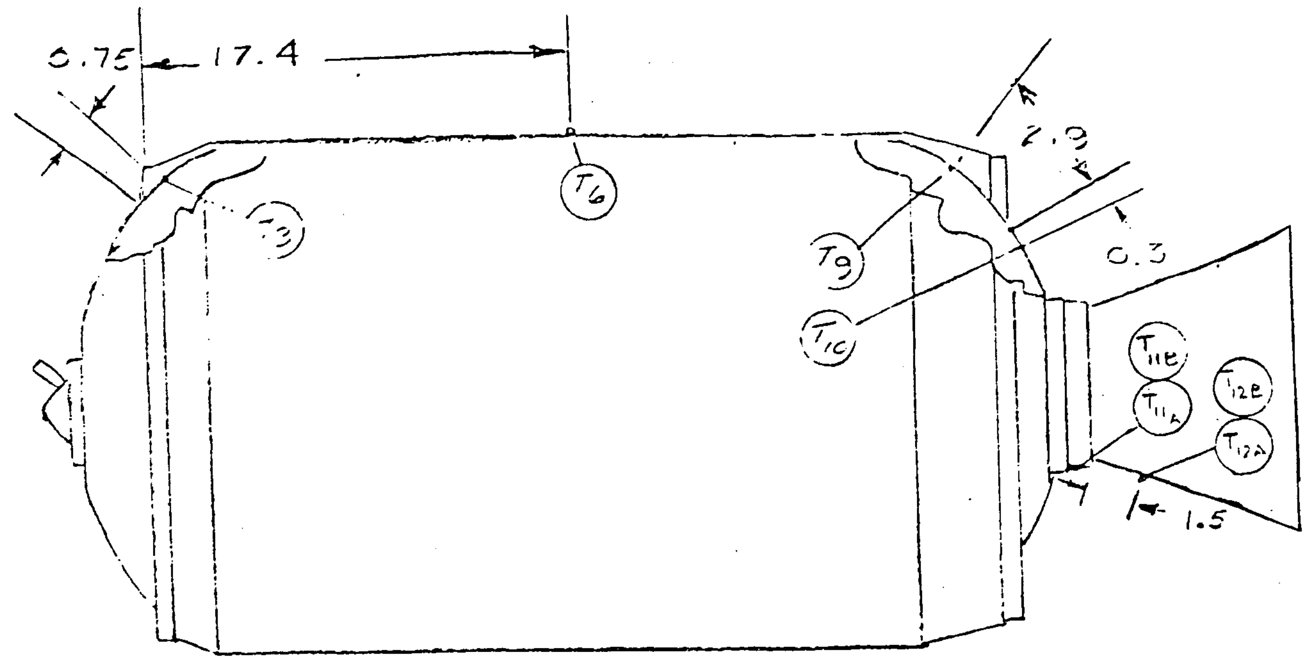
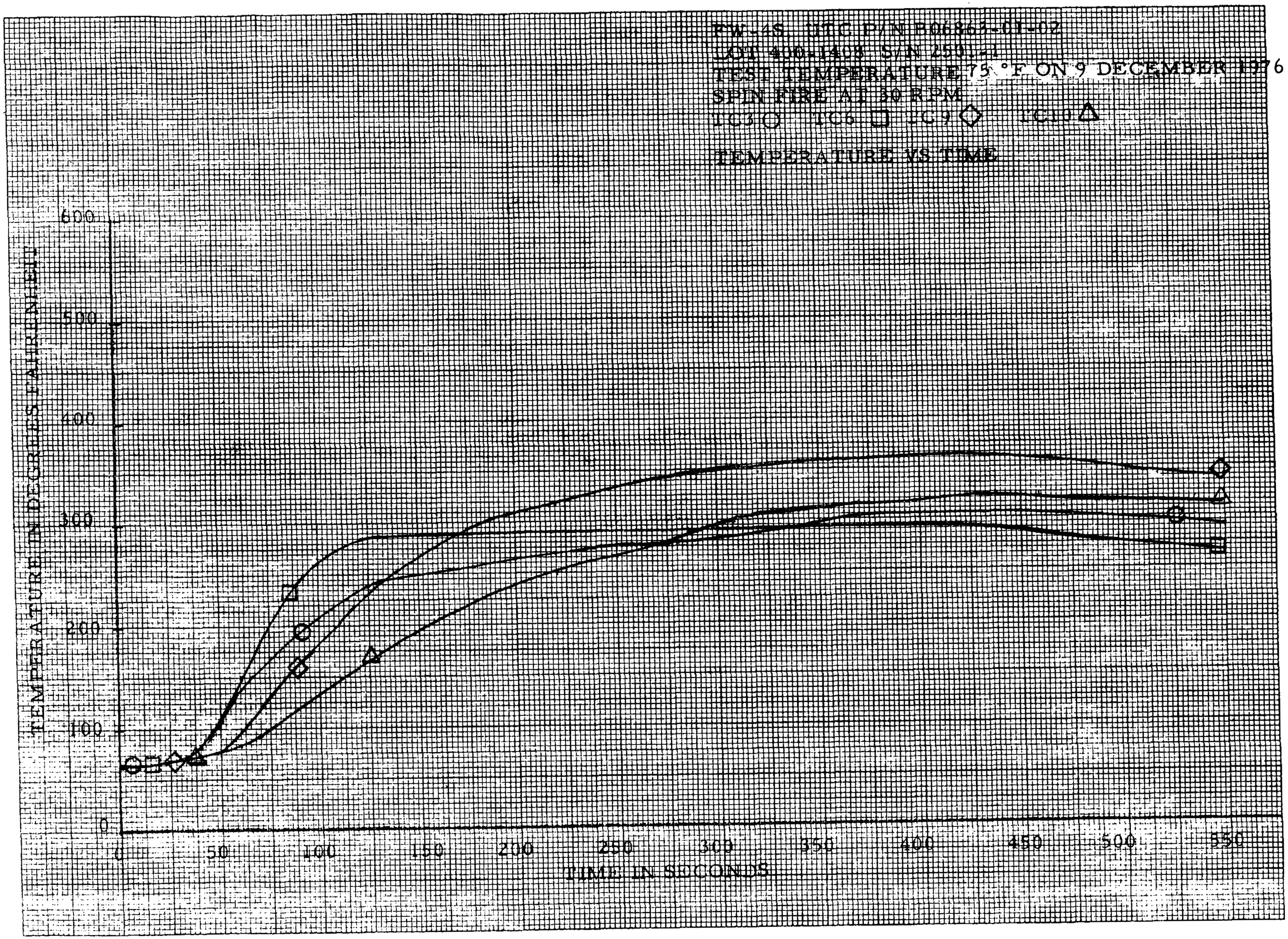
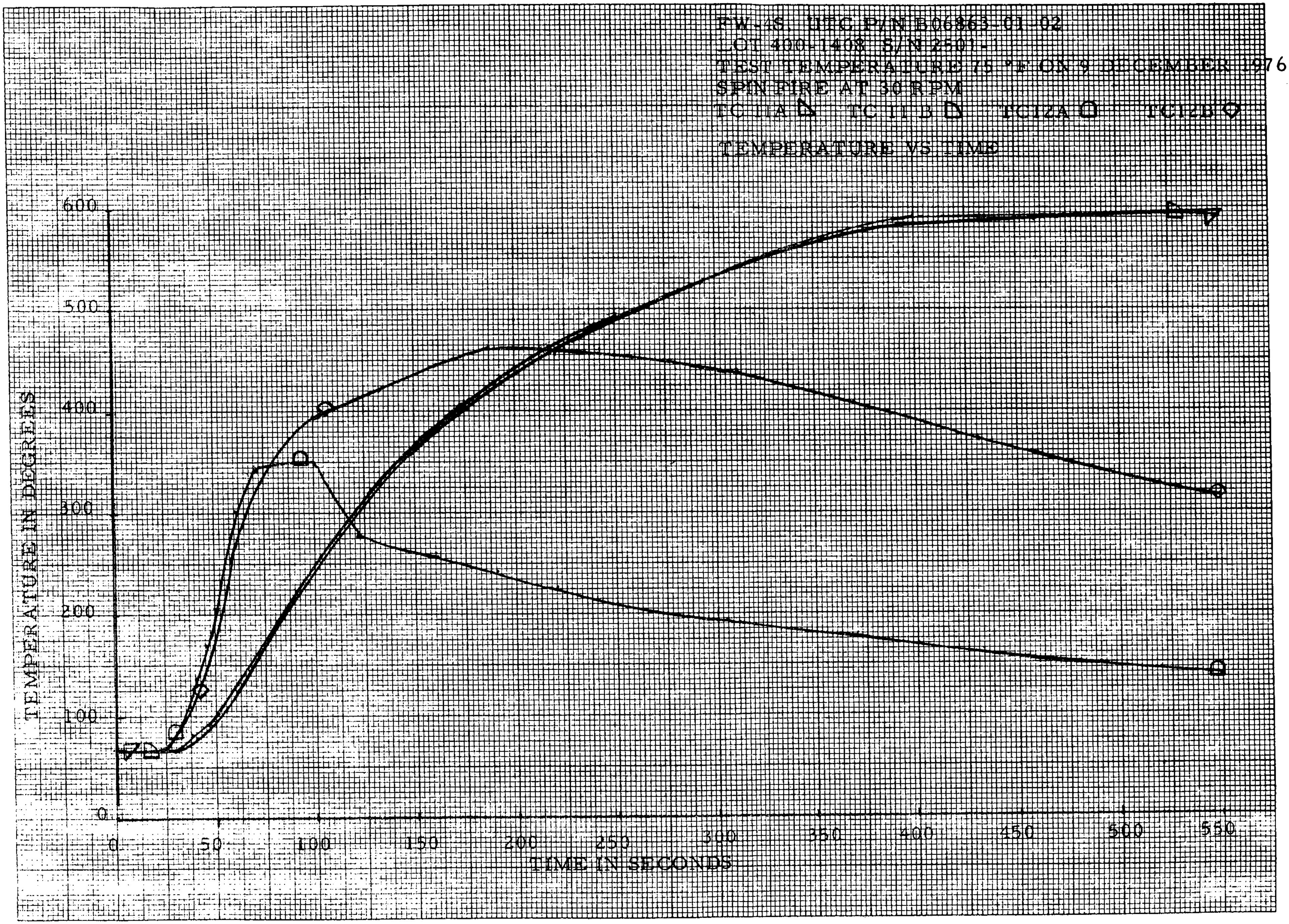


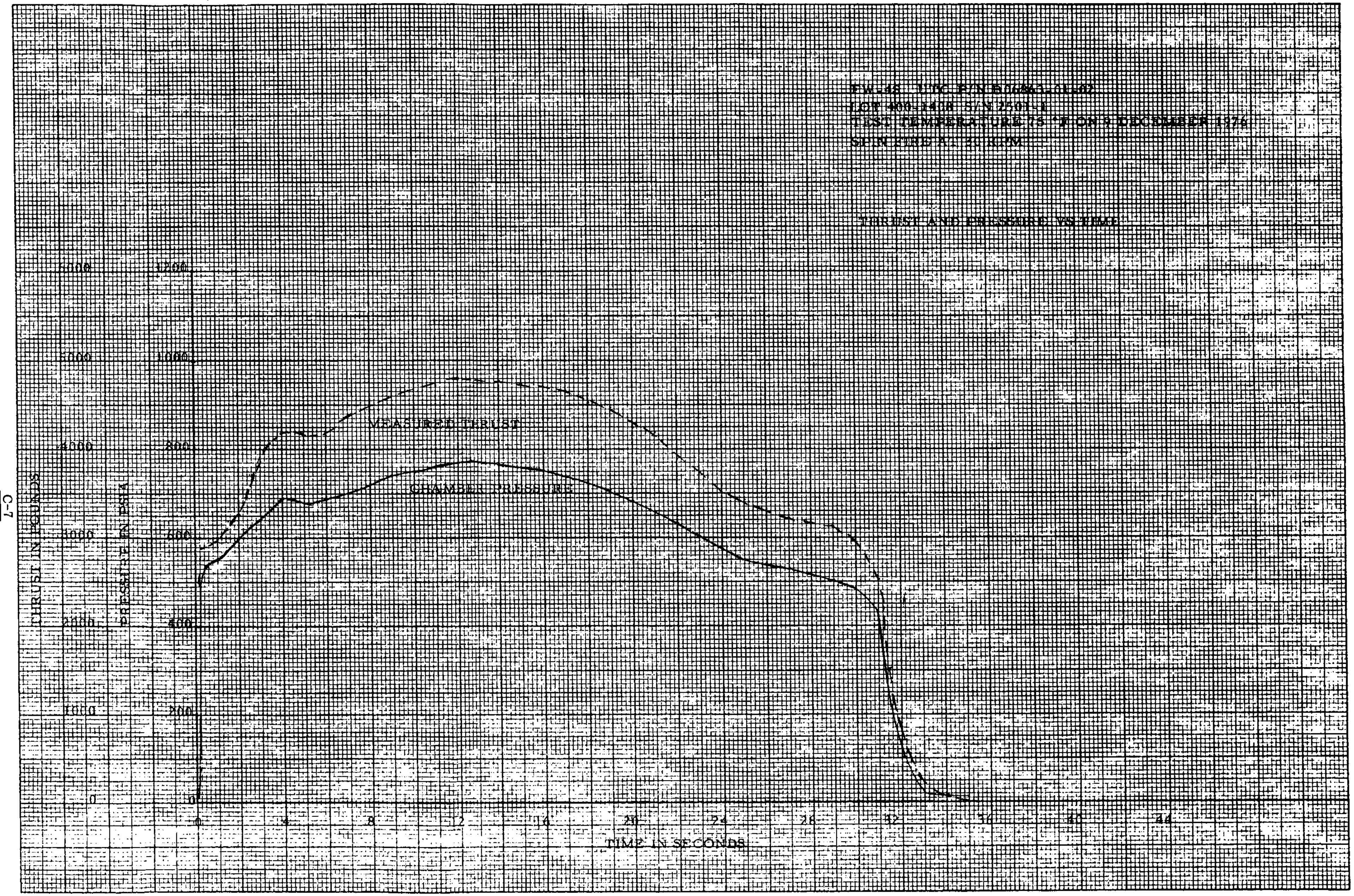
FIGURE 1. INSTRUMENTATION PLAN, ALTAIR III, THERMOCOUPLES

NOTES: 1. Thermocouples 11B and 12B to be located 90° from thermocouples 11A and 12A respectively.

2. Thermocouples 11A and 11B to be located as close to "corner" of aluminum adapter of nozzle as possible.


FW-4S, UTC P/N B06863-01-02
LOT 400-1408 S/N 2501-1
TEST TEMPERATURE 75 °F ON 9 DECEMBER 1976
SPIN FIRE AT 30 RPM
TC3 ○ TC6 □ TC9 ◇ TC10 △
TEMPERATURE VS TIME
TEMPERATURE IN DEGREES FAHRENHEIT
600
500
400
300
200
100
0
50
100
150
200
250
300
350
400
450
500
550
TIME IN SECONDS


FW-4S. UTC P/N E06863-01-02
LOT 400-1408 S/N 2501-
TEST TEMPERATURE 75 °F ON 9 DECEMBER 1976
SPIN FIRE AT 30 RPM
TC 11A
TC 11 B
TC12A
TC12B
TEMPERATURE VS TIME
TEMPERATURE IN DEGREES
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350
400
450
500
550
TIME IN SECONDS


FW-4S UTC P/N B06863-01-02
LOT 400-1408 S/N 2501-1
TEST TEMPERATURE 75 °F ON 9 DECEMBER 1976
THRUST AND PRESSURE VS TIME
MEASURED THRUST
CHAMBER PRESSURE
THRUST IN POUNDS
PRESSURE IN PSIA
TIME IN SECONDS
0
1000
2000
3000
4000
5000
6000
200
400
600
800
1000
1200
4
8
12
16
20
24
28
32
36
40
44

APPENDIX D

PROCEDURE FOR

REPLACEMENT OF NOZZLE THROAT INSERT, THIOKOL DRAWING: LO4935

THIOKOL CORPORATION
ELKTON DIVISION
ELKTON, MARYLAND

PROCEDURE

REPLACEMENT OF NOZZLE THROAT INSERT

THIOKOL DRAWING: LO 4935

DECEMBER, 1976

PREPARED BY: [signature] DATE: 12/1/76
Manufacturing Engineer

APPROVED BY: [signature] DATE: 12/1/76
Rocket Engineer

APPROVED BY: [signature] DATE: 12/2/76
Program Manager

The following procedure details the operations to be completed to replace the existing throat insert of a nozzle assembly with a new configuration. This new configuration is a carbide-graphite insert supplied by Los Alamos Scientific Lab of the University of California.

1. Position and clamp nozzle assembly, LO 4935, on lathe. Indicate 2.723 diameter (throat diameter) within .002 TIR and face of flange for best position shimming as required at aft exit plane of nozzle assembly.

2. Withdraw from stores finish machined carbide-graphite throat insert to be substituted for G-90 throat insert, measure 7^{o} 30' to 8^{o} 30' angle and maximum diameter as shown on Drawing LO 4934.

Angle ________________ Diameter ________________

3. Machine out G-90 throat insert in nozzle by machining at angle measured on carbide-graphite insert in Step 3. Machine until diameter at forward face of angle (largest diameter) is .022 greater than diameter measured in Step 3 on carbide-graphite insert. .018

NOTE: Do not remove material from exit cone.

4. Dry fit carbide-graphite throat insert for bondline thickness. Shim between exit cone forward face and aft throat insert face until shim is .033 to .061 thick and bondline gap is .008 to .012. Measure bondline gap using machinist clay at 3 locations.

Bond Gap ________________ Shim Thickness ____________

NOTE: Parts and adhesive shall be handled using clean white gloves during cleaning, adhesive application and assembly for cure.

5. Surface preparation and bonding. Wipe bonding surfaces of throat and throat insulator with MEK. Allow 15 minutes drying time. Hand sand with 40 to 120 grit paper, bonding surfaces of throat and throat insulator until uniformly abraded.

6. Apply zinc chromate putty on forward face of exit cone of thickness equivalent to shim used in Step 5 + .005. Bond surface to be free of zinc chromate putty.

7. Rinse with MEK. Wipe clean with cloth dampened with MEK. Check cloth for contaminants. Air dry 1 hour minimum. Bonding operation shall be performed within 8 hours of grit paper abrading. Cut HT-424 adhesive film on clean wax free paper. Place adhesive film flat on work bench and remove top polyethylene separator. Avoid wrinkling adhesive film. Place graphite throat on adhesive film and carefully wrap film around throat. Do not stretch film. Hold film on throat in place with masking tape at excess areas. Place shim strip under overlapping ends of adhesive film and cut through both layers of film simultaneously to establish a clean butt joint. Remove shim strip and holding film in contact with throat, remove polyethylene separator. Trim off excess adhesive film at both ends. Slip throat carefully on throat insulator without disturbing adhesive film. Place assembly on shop aid plates and torque 1/2 inch nut to 400 inch-pounds.

8. Place nozzle in oven and cure at 230 to 250^{o}F for 12 to 13 hours.

Cure Temperature ________ ^{o}F   Cure Time ____________ hours

9. Remove zinc chromate putty in gap between throat insert and exit cone for a depth of $0.13 \pm .03$.

10. Deliver nozzle to Quality Control for following inspection:

A. Perform alcohol wipe test of carbide-graphite throat and all exposed surfaces on plastic parts. Cracks of any size shall be cause for rejection.

Accept ___________   Reject ___________   ER No. __________

B. X-ray nozzle for defects with a minimum of 6 tangential views of throat insert to measure bond gap. Provide film to Engineering for evaluation.

APPENDIX E

TEST PLAN,
STATIC TEST OF 1000-POUND TEST MOTOR

THIOKOL CORPORATION
ELKTON DIVISION
ELKTON, MARYLAND

TEST PLAN

STATIC TEST OF 1000 LB TEST MOTOR

DECEMBER, 1976

PREPARED BY:	R E Black Project Engineer	DATE	1 Dec 76
APPROVED BY:	[illegible] Carson Rocket Engineer	DATE	1 Dec 76
APPROVED BY:	[illegible] Program Manager	DATE	1 Dec 76

TABLE OF CONTENTS

1.0 INTRODUCTION

This test plan details the requirements for the test of a 1000 lb spherical rocket motor.

2.0 SCOPE

This plan describes in detail the sea level test of a 1000 lb spherical motor.

3.0 TEST OBJECTIVES

3.1 The purpose of the static test is to evaluate the performance of a new nozzle insert configuration in a 1000 lb spherical motor when fired at 30 $\pm$ 5 RPM and $75^{\circ} + 5^{\circ}$F.

3.2 The motor shall be static tested after temperature conditioning at 75 $\pm$ 5°F for 48 hours minimum. The motor shall be tested while spinning at 30 $\pm$ 5 RPM under sea level conditions. Spin direction shall be counter clockwise as viewed from the nozzle end of the rocket motor.

4.0 TEST ARTICLE DESCRIPTION

4.1 The test motor is an elongated spherical rocket motor, designed for use on upper stage applications. The flightweight solid propellant rocket motor is approximately 30 inches in diameter with an overall length of 57 inches. The case is a titanium structure incorporating an aft end boss for nozzle installation. The nozzle configuration being evaluated utilizes a carbide-graphite composite throat insert in place of the standard Graphite G-90 insert. All other motor components are standard having been used in other test units. Individual components will have been subjected to visual, dimensional and radiographic inspections prior to incorporation in the motor assembly.

4.2 Prior to testing, the existing nozzles' graphite G-90 throat insert will be machined out and replaced with a carbide-graphite composite insert supplied by NASA. This operation will be completed using a Thiokol prepared Scout Project Office (SPO) approved procedure. The igniter for the motor will consist of a mixed charge of boron potassium nitrate pellets and propellant cubes contained in an elastomeric bag. This charge will be ignited by a smaller charge of boron potassium nitrate pellets also packaged within an elastomeric bag. This small charge will be initiated by an electrical initiator.

5.0 TEST DESCRIPTION

5.1 Static Test

5.1.1 The 1000 lb rocket motor shall be assembled in accordance with Thiokol Drawing E29438 with an igniter in place; shall be subjected to testing in accordance with the following plan.

5.1.2 The rocket motor of 5.1.1 shall be assembled in its test arrangement as described by LO 4741. The motor is to be installed into the thrust adapter (E18378-01) by means of a clamping ring (LO 4692) and 16-3/8-24UNF socket head cap screws with lockwashers. After installation the assembly shall be temperature conditioned at $75 \pm 5^{o}F$ for 48 hours minimum, then fired at sea level pressure while spinning about its axial center line at 30 RPM. Spin direction shall be counter clockwise as viewed from the nozzle end of the rocket motor.

5.1.3 Prior to assembly in the test arrangement, thermocouples will be installed on the assembly at locations as shown in Figure 1. Following installation of the motor into the test stand, the aft dome of the motor case and aft bulkhead down to the bulkhead nozzle exit cone interface shall be coated with insulation to protect these components from external heating. A radiant heat shield collar shall also be attached to the aft bulkhead using bolts in the jacking screw holes.

5.1.4 Data acquisition shall consist of measurements of motor chamber pressure, spin rate, external case and nozzle temperatures, and thrust. The spin rate shall be maintained for to + 60 seconds and temperatures should be monitored through to + 200 seconds. The parameters shall be recorded as indicated on Table I of this plan. The motor shall be quenched with dry powder within 60 seconds of the completion of propellant burning and a smother cover or stopper shall be installed over or in the nozzle as soon as possible after the motor has stopped spinning to prevent insulation burnout.

5.1.5 Ballistic test data presentation shall consist of plots versus time of pressures, temperatures, spin rate, and measured thrust. Integrals of the pressure and thrust channels shall also be determined and presented in a suitable data summary form.

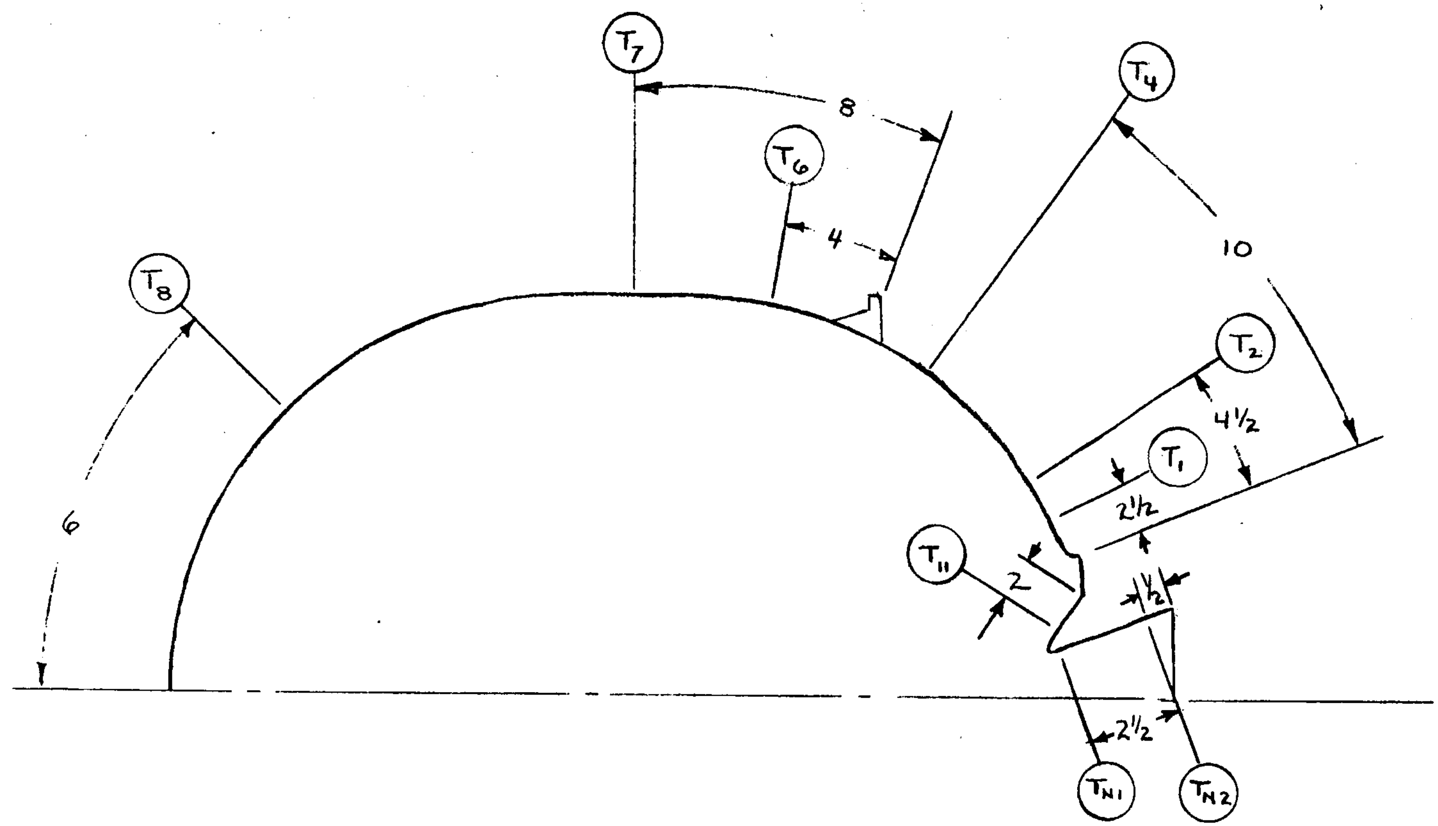
5.1.6 Physical measurements of pre and post-test nozzle throat and exit diameters shall be recorded (at 30^{o} intervals) as well as pre and post-test weights of the motor assembly and components. The hardware, particularly the nozzle components, will be studied after testing by techniques to be agreed upon with the Scout Project Office (SPO).

5.1.7 Still photographs of the pre and post-test motor assembly and test arrangement shall be made in detail as necessary.

5.1.8 One standard speed motor camera will be positioned to view the overall static test. Two high-speed cameras will be positioned on either side of the test bay for coverage during action time of the motor. A marking strip shall be located on the motor case in view of the cameras for use as a visual point of reference. See Figure 2 for schematic of camera locations. A clock with sweep second hand must appear in the camera field of view.

6.0 DATA REDUCTION

6.1 A data summary report of the ballistic results shall be prepared and shall include test date and time, temperature, nozzle dimensions (pre and post), motor weights, propellant weights, pressure and thrust integrals, burn time, action time, ignition delay, characteristic velocity, specific impulse, etc. The definitions of the ballistic parameters to be reported shall be consistent with previous test firings of this motor.



INSTRUMENTATION PLAN, THERMOCOUPLES

FIGURE 1.

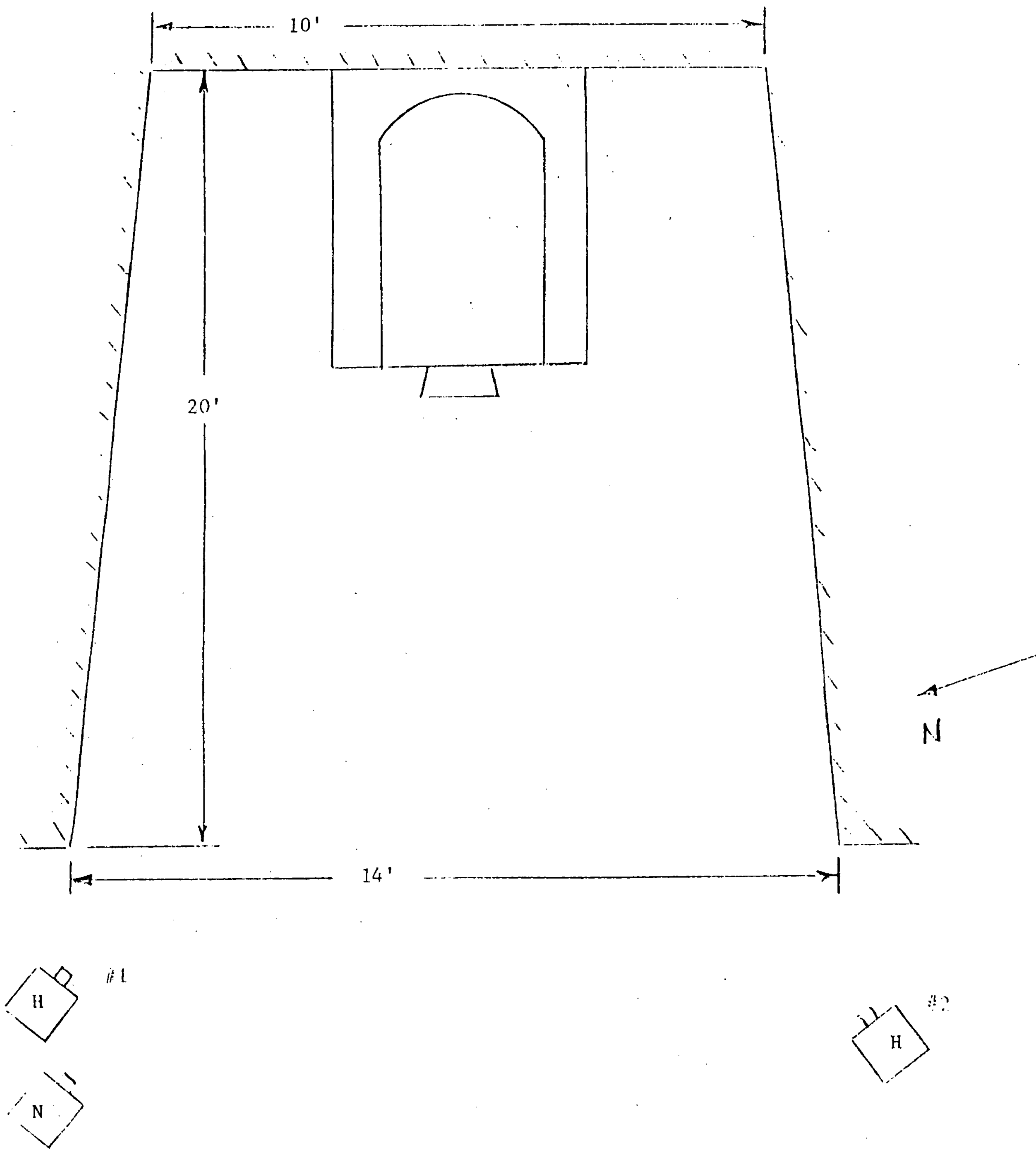


FIGURE 2. CAMERA ARRANGEMENT AND TEST CELL DESCRIPTION

NOTES:
1. N is a standard speed camera.
2. H is a high speed camera (400 fps).
3. Spin stand and motor not to scale.

TABLE I

Parameter	CEC	DIDACS	Remarks
P_{c_1} & $_2$	#1	1	O-1000 psig, utilize 8 slip rings
Motor Chamber Pressure	#2	13	
F_1 & $_2$	#1	15	O-10,000 lbf
Axial Thrust	#2	16	
T_1, T_2, T_4, T_6, T_7, T_8, T_{11}	#1		Chromel vs. Alumel 1100^{o}F max. temperature, utilize 14 slip rings
Temperature, Case & Closure			
T_{N_1}, T_{N_2}			
Temperature, Nozzle	#1		Chromel vs. Alumel 2000^{o}F max. temperature, utilize 4 slip rings
Spin Rate	#1		30 $\pm$ 5 RPM, continue for 60 seconds after test
	#2		
Ignition Current	#1		Provide 6.0 amps min. to single squib, utilize 2 slip rings
Zero Time	#1		
	#2		

NOTE: 1. Total number of slip rings utilized 28. CEC oscillograph recorder #1 to operate at 10.0 inches per second for about 60 seconds after zero time, then at 1 inch per second up to + 200 seconds. CEC #2 to operate at 10 inches/per second through the first 60 seconds after zero time.

2. Thermovision monitoring of the exhaust nozzle to be accomplished by NASA. AC power will be supplied by Thiokol for this equipment.

APPENDIX F

FIRING DATA SUMMARY, 1000-POUND TEST MOTOR

TESTING SECTION

BALLISTIC DATA SUMMARY

Engine Identification

1.	Project	2675
2.	Engine Type — Case S/N 0001	1000# Motor
3.	Engine Number	PV16-1386-1
4.	Test Date	27 January 1977
5.	Propellant	TP-H-3363A
6.	Trace Number	S-0826

Physical Data

1.	Propellant Weight, lbs.	1020.25
2.	Nozzle Throat Diameter: Before Test, inches	2.725
	After Test, inches	3.108
3.	Nozzle Exit Diameter: Before Test, inches	7.615
	After Test, inches	7.670
4.	Initial Throat Area A_{t_i}, in.^{2}	5.8321
5.	Final throat area, A_{tf}, in.^{2}	7.5867
6.	Average Nozzle Throat Area, A_t, in.^{2}	6.7094
7.	Initial Exit Area, A_{ei}, in.^{2}	45.5440
8.	Final Exit Area, A_{ef}, in.^{2}	46.2042
9.	Average Nozzle Exit Area, A_e, in.^{2}	45.8741
10.	Ambient Temperature at Time of Test, °F	36
11.	Engine Conditioned Temperature for Test, °F	+75
12.	Initial K_n (I)	NA
13.	Average K_n (A)	NA
14.	Nozzle Expansion Ratio	6.837

Engine Number PV16-1386-1

Time Data

1.	Ignition Delay, t_d, Sec.	1.36
2.	Burning Time, t_b, Sec.	59.56
3.	Action Time, t_a Sec.	60.74
4.	Ratio of t_a/t_b	1.02
5.	Burning Rate, Average, in./sec. Web. 12.49 in.	0.2097

Pressure Data

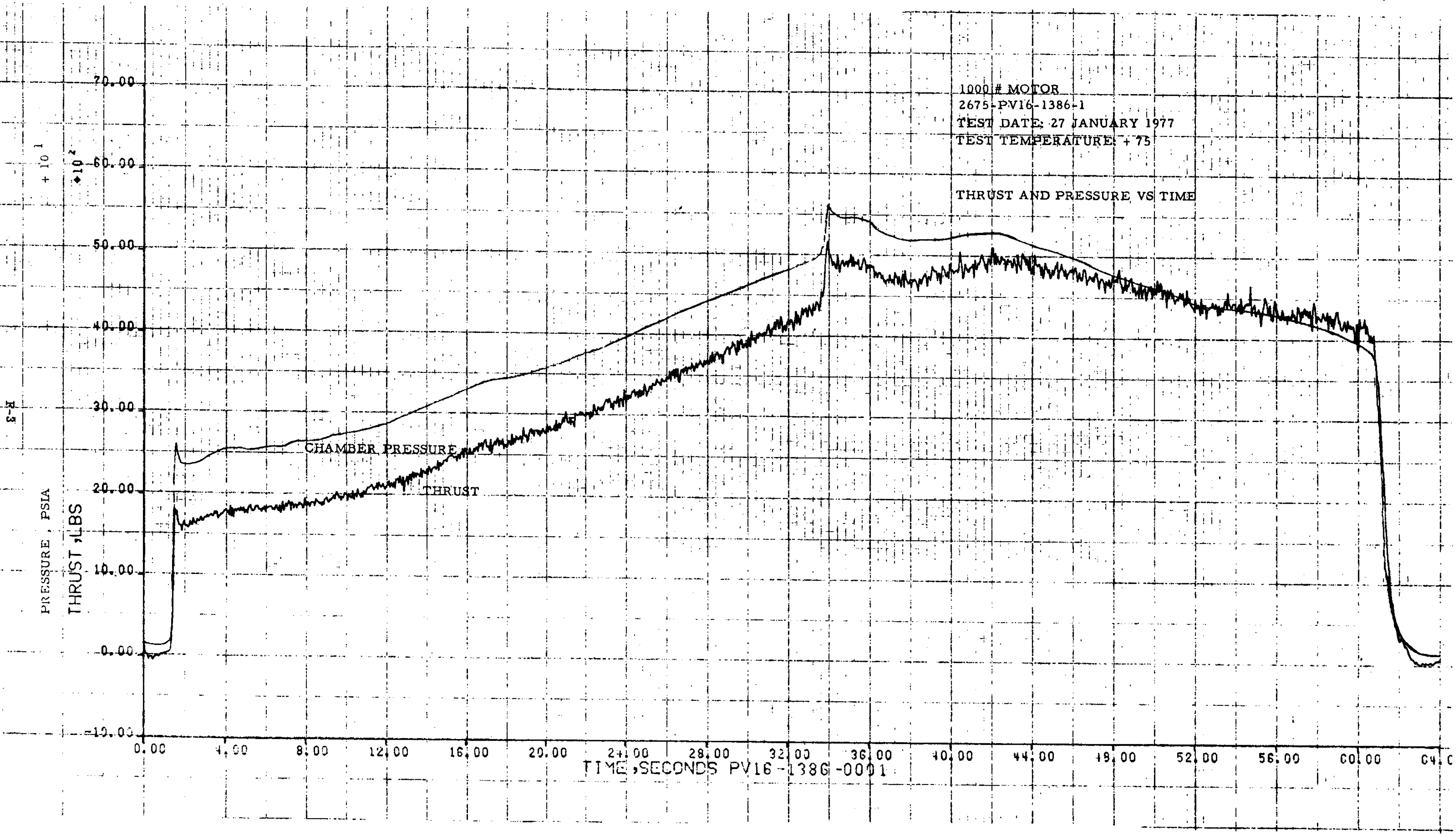
1.	Maximum Pressure, Pmax, psia	577
2.	Average Pressure, Pavg, psia	409
3.	Initial Pressure, psia	238
4.	$\int$ Pdt, psia-sec.	24589
5.	Characteristic Exhaust Velocity, C*, ft./sec.	5200

Thrust Data

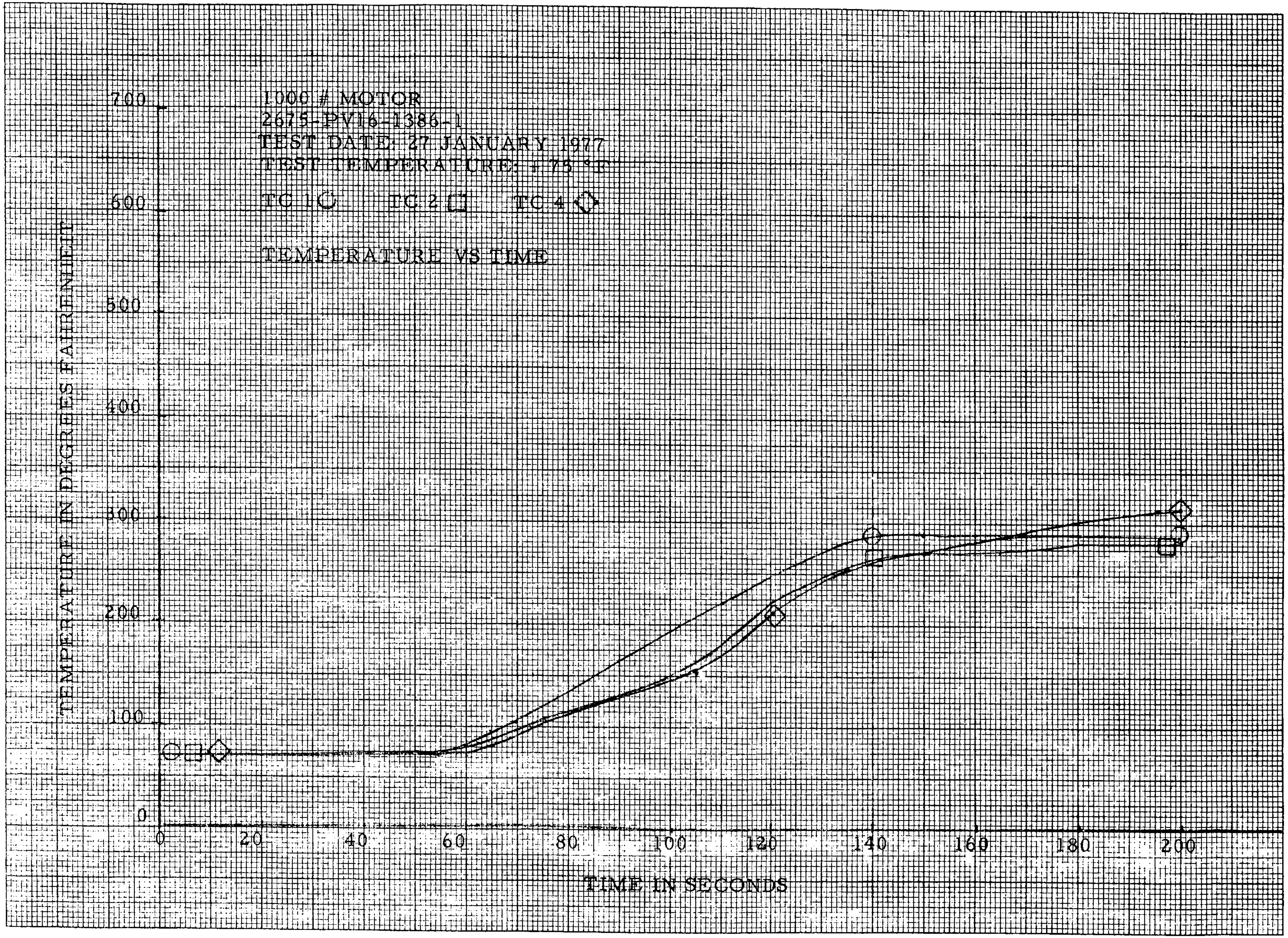
1.	Maximum Thrust, lbs.	5219
2.	Average Thrust, lbs.	3597
3.	Initial Thrust, lbs.	1579
4.	$\int$ Fdt, lb.-sec.	216053
5.	Propellant Specific Impulse, Isp, lbs.-sec./lbs.	211.8
6.	$C_f C_d$	1.31

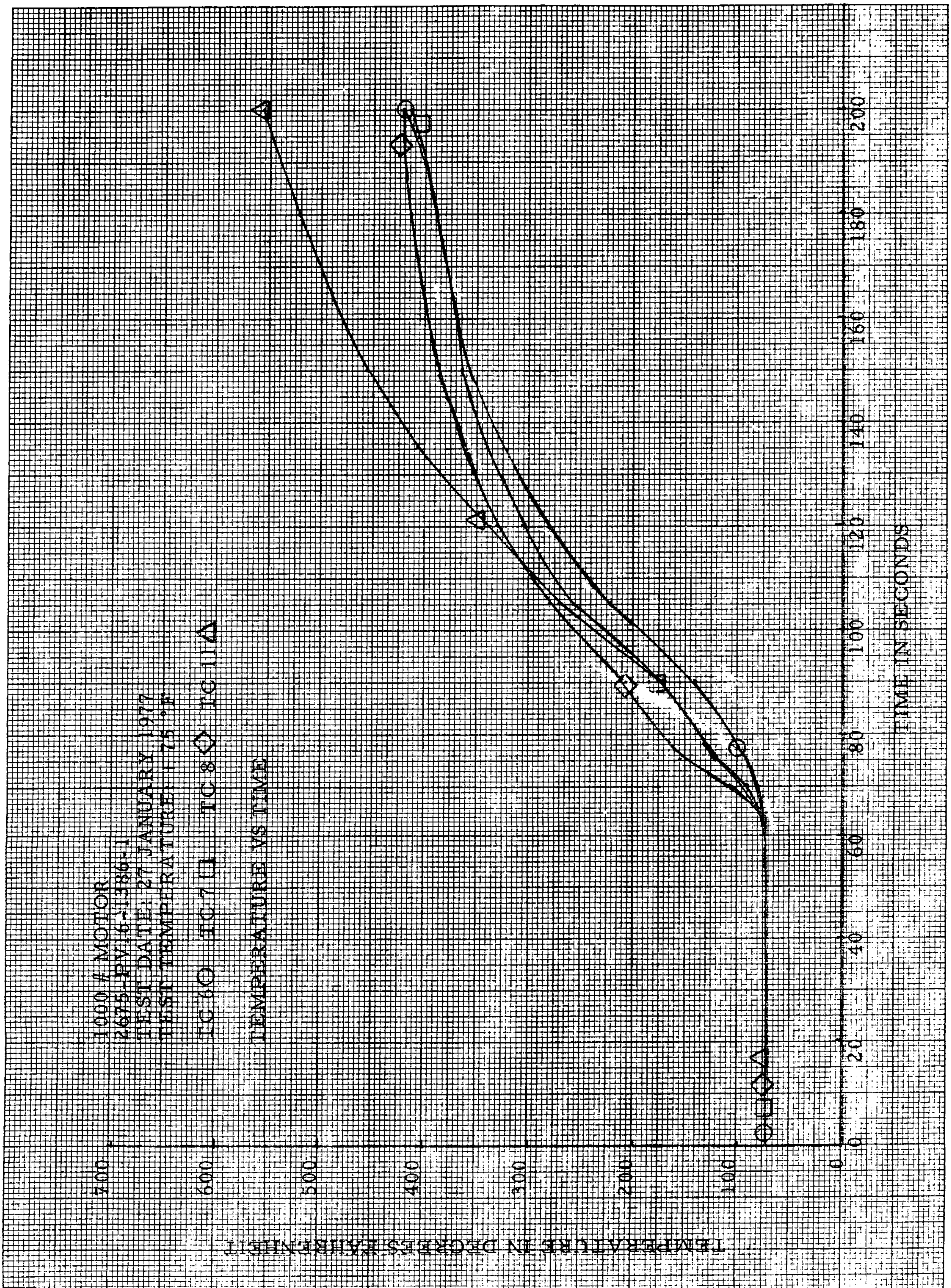
Remarks:
1) Spin Rate 30 RPM
2) Special carbide nozzle throat insert

TF-5168
RE-3-20 (2)

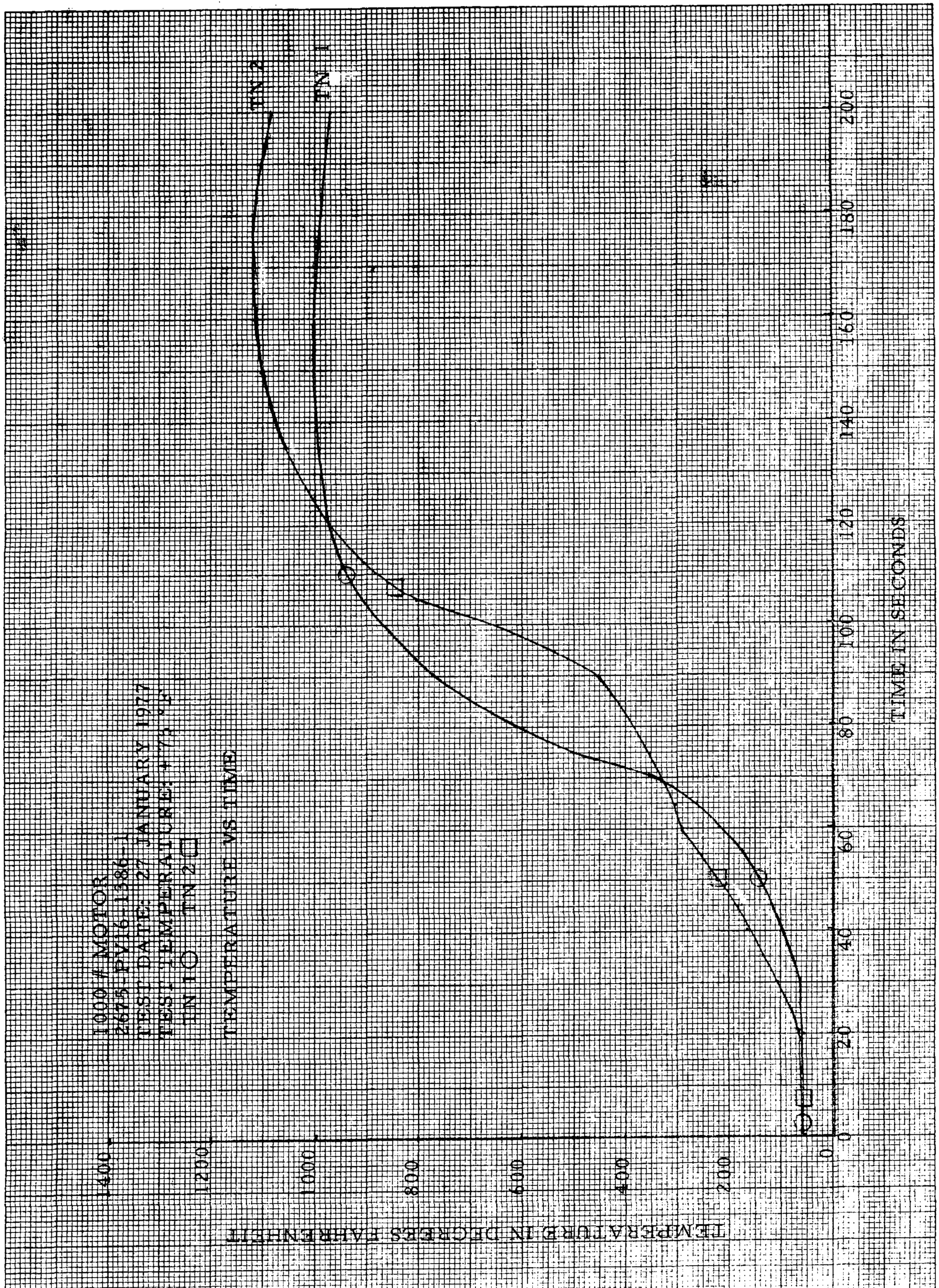


1000# MOTOR
2675-PV16-1386-1
TEST DATE: 27 JANUARY 1977
TEST TEMPERATURE: + 75
THRUST AND PRESSURE VS TIME
CHAMBER PRESSURE
THRUST
PRESSURE , PSIA + 10 1
THRUST ,LBS ♦10 2
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
44.00
48.00
52.00
56.00
60.00
64.0
TIME ,SECONDS PV16-1386-0001


1000 # MOTOR
2675-PV16-1386-1
TEST DATE: 27 JANUARY 1977
TEST TEMPERATURE: + 75 °F
TC 1 ○   TC 2 □   TC 4 ◇
TEMPERATURE VS TIME
TEMPERATURE IN DEGREES FAHRENHEIT
0
100
200
300
400
500
600
700
0
20
40
60
80
100
120
140
160
180
200
TIME IN SECONDS



1000 # MOTOR
2675-PV16-1386-1
TEST DATE: 27 JANUARY 1977
TEST TEMPERATURE: 75°F
TC 6 ○ TC 7 □ TC 8 ◇ TC 11 △
TEMPERATURE VS TIME
TEMPERATURE IN DEGREES FAHRENHEIT
0
100
200
300
400
500
600
700
TIME IN SECONDS
0
20
40
60
80
100
120
140
160
180
200


1000 # MOTOR
2675-PV16-1386-1
TEST DATE: 27 JANUARY 1977
TEST TEMPERATURE: + 75 °F
TN 1 ○ TN 2 □
TEMPERATURE VS TIME
TN 2
TN 1
TEMPERATURE IN DEGREES FAHRENHEIT
1400
1200
1000
800
600
400
200
0
20
40
60
80
100
120
140
160
180
200
TIME IN SECONDS